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January 1996

Structural Parameter Analysis of U.S. Army Corps of Engineers Existing Intake Tower Inventory

by Richard C. Dove

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Final report

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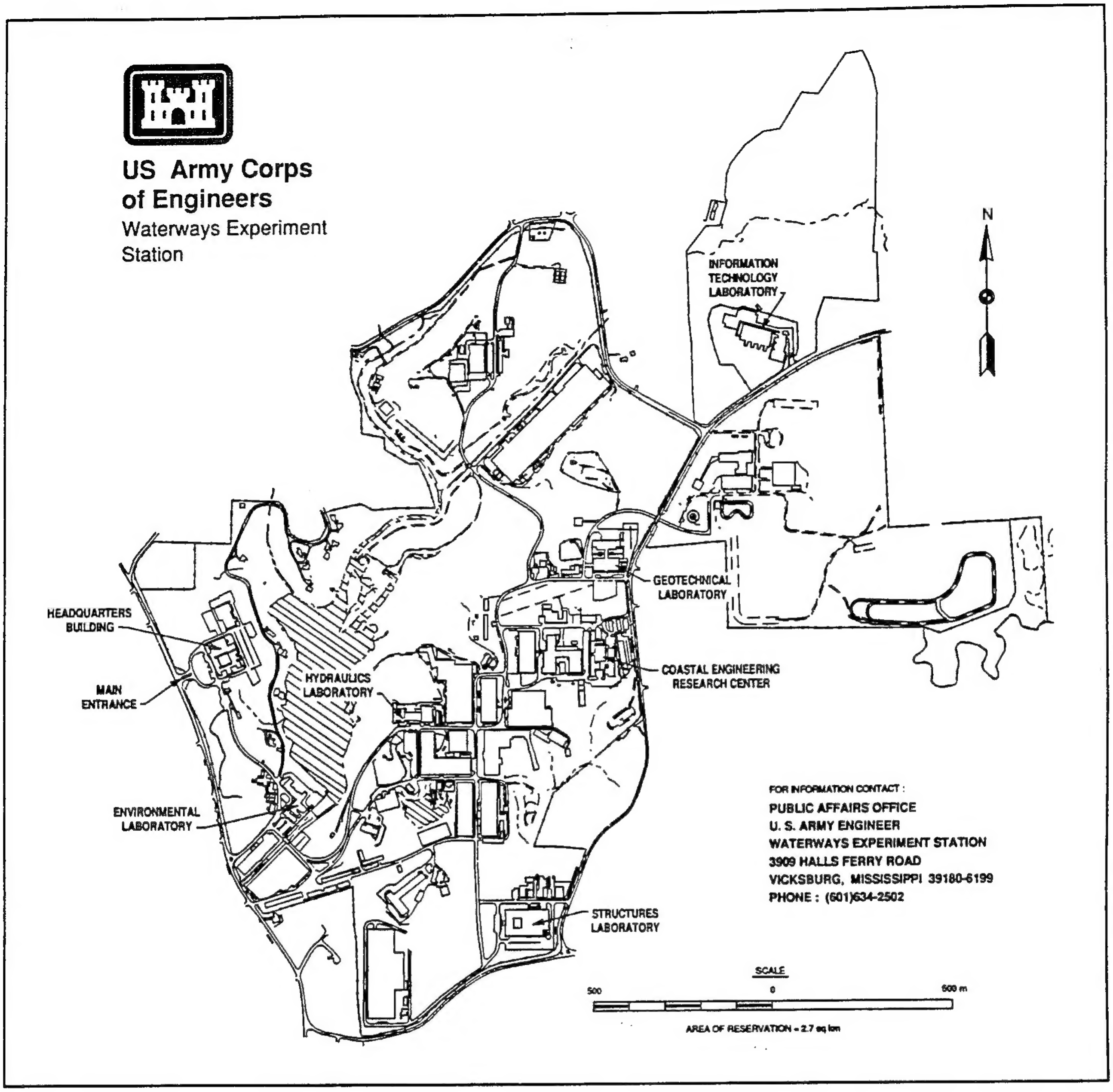

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Preface

The research reported herein was sponsored by Headquarters, U.S. Army Corps of Engineers, under Research Program 387 - Earthquake Engineering - Structures, Work Unit 32911, Nonlinear Dynamic Response and Failure Mechanisms of Intake Towers.

The principal investigator was Mr. Richard C. Dove, Structural Mechanics Division (SMD), Structures Laboratory (SL), U.S. Army Engineer Waterways Experiment Station (WES). Dr. Mary Ellen Hynes, Geotechnical Laboratory, was Program Manager for Research Program 387 - Earthquake Engineering - Structures. This research project was carried out under the general supervision of Mr. Bryant Mather, Director, SL; Mr. John Ehrgott, Assistant Director; and Dr. Reed Mosher, Chief, SMD. The work was conducted during the period June-November 1994 under the direct supervision of Mr. Dove. Mr. William Dzurick, a contract student from University of Arizona, assisted in the compilation of structural data.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Multiply	By	To Obtain
feet	0.3048	metres
inches	25.4	milimetres
pounds (force)	4.448	newtons
pounds (force) per square inch (psi)	0.006894757	megapascals

1 Introduction

Background

In the event of an earthquake, it is vitally important that the catastrophic failure of a dam and subsequent sudden release of the reservoir be prevented. An important part of the prevention of such a failure is maintaining the ability to control the release of water after the earthquake. If a dam is damaged, the prompt and controlled lowering of the water level will remove hydrostatic pressure that will help to prevent the propagation of the damage into a catastrophic failure. For most earthen dams, the release of water is controlled through a reinforced concrete intake tower. The functional survival of such towers is therefore very important and is the main concern of this research effort.

It is difficult to determine if existing intake towers of outlet works of dams are sufficiently ductile to resist major earthquakes in all structural failure mechanisms. Most existing Corps intake towers are lightly reinforced concrete structures that were designed using the seismic coefficient method which incorrectly estimates demands placed on an intake tower during a major earthquake. Lightly reinforced concrete structures, such as the Corps intake towers, may have sufficient inherent ductility to respond without failure. However, the success of the tower in resisting failure is dependent upon the magnitude of the earthquake loads and the structural details controlling the nonlinear dynamic response and failure mechanisms of the specific tower. Currently, available analysis tools and engineering guidance for intake towers do not properly include these factors. The development and validation of better tools and guidance is the primary goal of Research Program 387 - Earthquake Engineering - Structures, Work Unit 32911, Nonlinear Dynamic Response and Failure Mechanisms of Intake Towers. The research conducted and reported in this report is the initial step in a planned 7-year effort to accomplish this goal.

The overall approach of the research program to be conducted under this work unit is to concentrate on evaluating the inherent ductility of existing intake towers. As will be covered in this report, the initial effort has included an analysis of existing intake towers to examine their location hazard and the variation of structural parameters. A field advisory committee of cognizant Corps engineers was formed to help guide the survey as well as assist in the planning of the research effort. Input will also be solicited from recognized experts in this area of study to assure complete utilization of existing

intake towers. Primarily, the overall research effort will be a computational and experimental effort to generate a valid structural model representative of those found in the population of existing intake towers. It is expected to include an examination of the performance of reinforcing bar details (lap lengths, development lengths, bond forces, and joint details), structural component and substructure testing (compression, shear, and moment effects), model tower testing (failure mechanisms and bridge/tower interaction), and perhaps nondestructive and destructive testing of full-scale prototype tower. Computational efforts will include concrete material model evaluation and modification. The hydrodynamic effects of water inside and outside of towers will also be considered. The goal will be the development of usable computational tools and engineering guidance for the evaluation and retrofit of existing intake towers and for the design of new towers.

The greatest benefit from this effort is the potential savings realized by a reduction in the need for retrofit strengthening of existing intake towers. Approximately 77 intake towers are in seismic zones 2 and above. Based on experience in the Pacific Northwest, it is estimated that retrofit of an existing tower will cost approximately $5 million. Hence, total savings could exceed $100 million if it can be demonstrated that the inherent ductility available in even a minority of existing intake towers is sufficient to resist earthquake demands.

Objective

The overall objective of this research program is to develop verified nonlinear analysis techniques for determining the ductility of existing intake towers under earthquake loads for all potential structural failure mechanisms, to develop analysis procedures to account for this ductility, and to provide design and retrofit guidance for intake towers. The specific objective of the tower inventory analysis is to quantify the distribution and variation of the structural characteristics of the U.S. Army Corps of Engineers (USACE) inventory of existing intake towers as relating to their earthquake location hazard. It is expected that the analysis will assist in the identification of possible failure mechanisms and help quantify the extent of the problem of the seismic response of existing towers. The information generated will also be used in the planning of intake tower shear wall component tests scheduled for FY 95 as well as subsequent substructure, reinforcing detail, failure mechanism, and bridge/tower interaction experiments. The results of these tests will used to develop and/or validate nonlinear analysis techniques for structures typical of those observed in Corps intake towers. These validated nonlinear analysis techniques will be applied to the development of approximate and/or simplified analysis procedures for the evaluation of the ductility of existing intake towers, hence fulfilling the overall objective of the entire research program.

Approach

The approach of the tower inventory analysis was to build upon an initial effort conducted under the Repair, Evaluation, Maintenance and Rehabilitation Research (REMR) Program 120, Work Unit 32642. This initial study was performed to identify the characteristics of the intake towers of Corps dams as they relate to Uniform Building Code seismic zones. This effort included information compiled in 1993 by Mr. Dave Illias, U.S. Army Engineer District, Portland. Additional information was gathered from a search of design memoranda and inspection reports found in the U.S. Army Engineer Waterways Experiment Station (WES) research library. The National Inventory of Dams was also consulted. Of the 162 intake towers identified in this study, 77 were in seismic zones 2 and greater.[1] The available information on the properties of these 77 towers was statistically analyzed. The tower characteristics included in the analysis were: total height, clear height, major and minor widths, height-to-width ratio, and concrete wall thickness.

In conducting the initial survey, it was evident that only limited structural information was available from the sources cited. As a result, the first step in the tower inventory analysis was to obtain structural drawings of the 77 towers of interest from the corresponding Corps districts. In all, 13 district offices were contacted and all responded by sending the requested drawings and information. These drawings formed the basis of the inventory analysis conducted. As will be discussed in this report, each drawing was analyzed to determine the geometric and material properties of the towers, this information was entered in a database, and a statistical analysis was performed on the data to summarize the results.

[1] *Uniform Building Code.* (1991). International Conference on Building Officials, Whittier, CA.

2 Inventory Analysis

General

The inventory analysis began with an examination of the structural drawings of the towers of interest. It was evident that these structures were relatively complex and the structural configuration varied considerably from tower to tower. However, the towers were similar enough that descriptive parameters could be developed that would allow meaningful comparisons among the population. These parameters were determined for each tower, incorporated into a spreadsheet/database, and descriptive statistics developed.

Database Development

There are many parameters that must be known to conduct a ductility analysis of a concrete intake tower. The parameters needed include the geometric and material properties of the tower as well as the expected loading. To develop and/or validate ductility analysis procedures for existing towers, the variation of these parameters in the tower population must be well understood. The generation of this spreadsheet is part of an effort to quantify the variation of important structural parameters in the population of existing Corps intake towers in areas of significant seismic risk. Statistical measures of this variability will be used in the planning and design of experimentation and analysis efforts.

For most intake structures, the geometry varies considerably throughout the height of the tower. It is common to have a very massive substructure at lower elevations with a much less massive tower at higher elevations (Figure 1). The substructure typically consists of the intake (including log racks) and outlet conduit. The towers usually contain water quality gates and all flow rate control mechanisms. At the top of the tower, there is often a superstructure. The superstructure usually extends above the service bridge and is commonly located where the control station is. The superstructure is normally above the maximum water surface and is often a structurally distinct component of the intake tower.

Since most intake structures vary in cross section considerably throughout the height of the tower, it was necessary to determine certain critical cross sections where the tower would be most likely to fail. The most common critical cross section was at the intersection of the tower and the substructure.

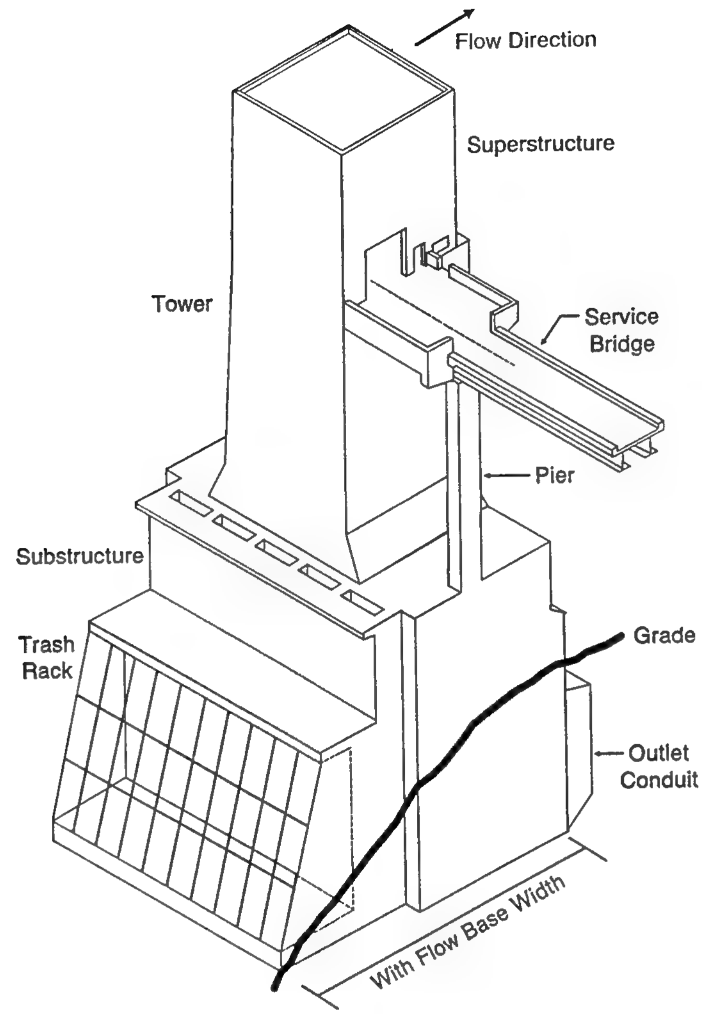

Figure 1. Typical rectangular intake tower

In some cases the geometry of a tower led to the identification of two critical sections, one for bending about the flow axis as well as one for bending about an axis perpendicular to the flow. The flow axis is defined as the direction of the flow of the water through the conduit. For most rectangular towers these two axes coincided with the major axes of the structure. For any tower with two critical sections, the spreadsheet is arranged so that information for the cross section about the flow axis is listed in the row above the row containing information for the critical section of the axis perpendicular to the flow.

The selection of critical sections was made by inspection and was based upon apparent large changes in stiffness at the lowest elevation in the free standing (not embedded) part of the tower. These cross sections are not intended to identify an exact point of failure, but they are meant to identify a cross section typical of one in an expected failure zone.

Once the critical cross sections were chosen, some idealization was needed to concisely represent the structure. For rectangular cross sections, the structure was idealized as a series of shear walls. Each section has shear walls in the direction of flow and in the direction perpendicular to the flow. This idealization ignores relatively minor variations in thickness, small penetrations, and other minor departures of the actual geometry from that of an assumed rectangular section. The rectangular section was always chosen as a conservative approximation of the typical actual section. From the chosen wall section, the typical wall reinforcement was identified, and both the vertical percent of steel (rho gross vertical) and horizontal percent of steel (rho gross horizontal) were calculated based on a unit width of the section. These ratios are meant to provide a rough estimate of the actual reinforcement. Special rebar placed for cutouts, corners, etc., were not considered. The selection of typical reinforcement was complicated by the fact that additional reinforcement was usually present in the transition zone between the substructure and the tower. To overcome this problem, the reinforcement was chosen at the lowest point above the critical section which appeared to represent the typical reinforcing. For circular and octagonal sections, a similar process was followed for the identification of reinforcement. Rho gross vertical was calculated as the total reinforcement divided by the area of concrete, while rho gross horizontal was still calculated using a unit width of the section.

Determining the area properties of sections required a number of assumptions and simplifications due to the complexity of the geometry of individual critical cross sections. Most of these assumptions consisted of regularizing the geometry by neglecting the contribution of relatively minor structural components such as small wing walls or penetrations. It was not practical to completely describe all such simplifications in the spreadsheet. A record was kept of the assumptions made for each tower for later reference. All pertinent data and calculations are also recorded. All information was obtained from as-built drawings and other available literature such as design memorandums.

Table 1 describes the parameters presented in the spreadsheet and briefly explains how they were determined. All heights are based upon the base of the structure unless otherwise indicated. The base of the structure is defined as the lowest point of concrete common to the entire intake structure. The spreadsheet itself is contained in Appendix A.

Summary Statistics

The summary statistics of average and standard deviation were included in the intake tower spread sheet containing the primary intake tower characteristics (Appendix A). Additional summary statistics and a graphical presentation of the distribution of several of the more important characteristics will now be provided. More importantly, secondary characteristics derived from the primary characteristics will be presented and summarized.

Table 1
Description of Intake Tower Database Parameters

Project	Dam or reservoir for which parameters are given
District	Corps district in which the project is located
Year built	Approximate year in which the project was built
Zone	Seismic zone in which the project is located (from 1991 zoning)
Type	Shape or description. R = rectangular, C = circular, O = octagonal, I = Inclined, COL = column supported
Maximum pool	Height of maximum pool
Conservation pool	Height of normal pool
Minimum pool	Minimum expected pool
Total height	Height to highest point of structure
Base width parallel with flow	Width at base along the flow axis, including trash racks, not including transition conduit unless sufficiently rigid
Base width perpendicular with flow	Width at base along an axis perpendicular to flow, through the maximum width of the base
Base to service bridge	Height from the base to the service bridge floor
Base to critical section	Height from the base to the assumed critical section, note there may be two such heights, see explanation above
Base to top of conduit	Height from the base to the point of extension of the transition conduit outward from the main substructure
Base to average embedment	Height from the base to the approximate average elevation of embedment
fy	Yield strength of reinforcing bars used in the structure
f_c	Concrete compressive strength after 28 days
Clear height at critical section	Height difference from top of the structure to the critical section
Critical section width parallel to flow	Width of structure at critical section in direction of flow, note for circular and octagonal section this information is omitted
Critical section width perpendicular to flow	Width of structure at critcal section in direciton perpendicular to flow, see note above
Ag at critical section	Gross area of critical cross section, calculated as product of maximum widths in both directions for rectangular sections, approximate area enclosed by seciton for other geometries
N.A. distance parallel with flow	The maximum distance between neutral axis and extreme fiber fo the critical section in the direction of flow
N.A. distance perpendicular to flow	The maximum distance between neutral axis and extreme fiber fo the critical section perpendicular to the direciton of flow
Ig about flow axis	Moment of inertia about centroidal axis parallel-to-flow

(Continued)

Table 1 (Concluded)	
Ig about axis perpendicular to flow	Moment of inertia about centroidal axis perpendicular-to-flow
Length	Length of wall with assumed constant thickness
Thickness	Thickness of wall corresponding to length above
Vertical steel inside face	Typical vertical steel reinforcement used on the inside face of the wall as viewed from the centroid of th estructure, see explanation above
Vertical steel outside face	Typical vertical steel reinforcement used on the outside face of the wall as viewed from the centroid of the structure, see explanation above
Rho vertical	Calculated gross vertical reinforcement ratio
Horizontal steel inside face	Typical horizontal steel reinforcement used on the inside face of the wall as viewed from the centroid fo the structure, see explanation above
Horizontal steel outside face	Typical horizontal steel reinforcement used on the outside face of the wall as viewed from the centroid fo the structure, see explanation above
Rho horizontal	Calculated gross horizontal reinforcement ratio
Cover inside face	Clear distance between reinforcement and face of wall for inside face as viewed from centroid of structure
Cover outside face	Clear distance between reinforcement and face of wall for exterior face as viewed from centroid of structure
Area of shear wall	Area calculated as product of length by thickness of rectangular sections, not applicable to nonrectangular sections

Figure 2 shows the distribution of the decade of design of the towers examined. The date of design was taken as the initial date of the as-built drawings for each tower. The distribution shows that the majority of the towers were designed in the 1950 to 1970 time span. The average design date was 1960 with a standard deviation of 11 years. This information may be useful in the examination of the codes and design criteria applied to these towers.

The distribution of the total height of the towers is shown in Figure 3. Height is a very important factor in the earthquake analysis of a structure in that the fundamental frequency of response of a structure with a given mass and stiffness distribution is largely dependent upon the height. The mean total height for tower population was 165.5 ft[1] with a standard deviation of 63.3 ft.

A characteristic related to the total height is the height-to-base ratio. This parameter is important in the consideration of possible rigid body overturning of the towers and is defined as the ratio of the total height of a tower divided by the length of the base of the tower. For most towers, there are two major axis

[1] A table of factors for converting non-SI units of measurements to SI (metric) units is presented on page vii.

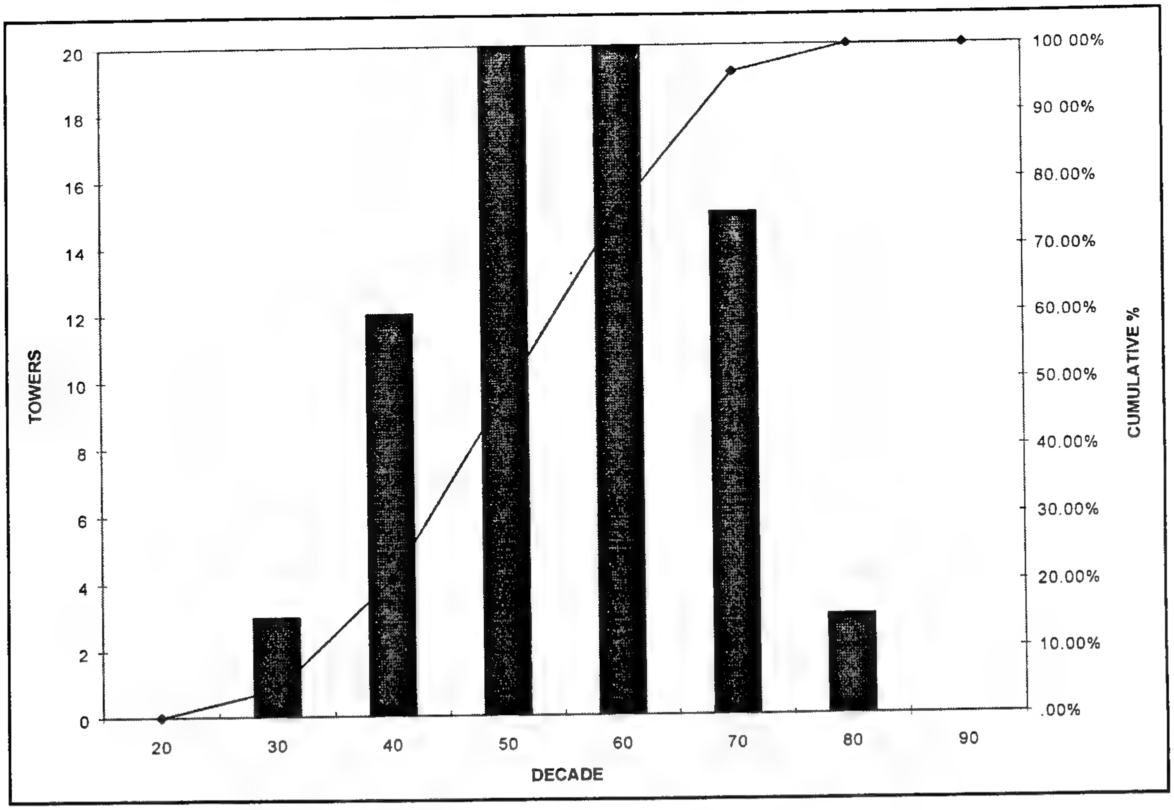

Figure 2. Distribution of towers by decade of design/construction

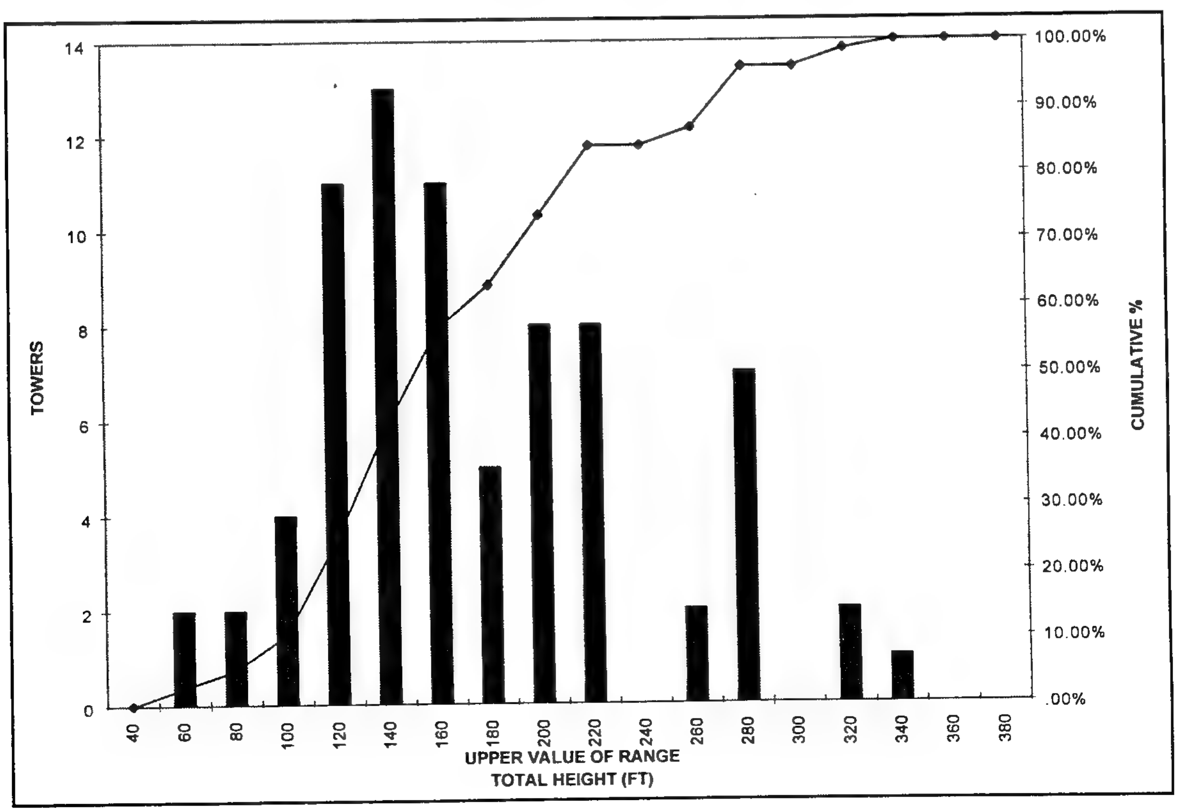

Figure 3. Distribution of towers by total height

directions that can be defined as the parallel-to-flow direction and the perpendicular-to-flow direction. In both rectangular and nonrectangular towers, the base length may be deferent for these two major axis and hence two height-to-base ratios were calculated for each tower. Figure 4 shows the distribution of height-to-base ratios for rectangular towers. Figure 5 shows the distribution of height-to-base ratios for rectangular towers with both axis directions shown separately. The mean ratio for the parallel-to-flow direction was 2.49, the standard deviation was 0.84, the minimum was 0.91, and the maximum was 5.27. The mean ratio for the perpendicular-to-flow direction was 3.31, the standard deviation was 0.98, the minimum was 1.34, and the maximum was 6.29. Similarly, Figure 6 shows the distribution of height-to-base ratios for nonrectangular towers. Figure 7 shows the distribution of height-to-base ratios for nonrectangular towers with both axis directions shown separately. In this case, the mean ratio for the parallel-to-flow direction was 3.23, the standard deviation was 0.72, the minimum was 2.31, and the maximum was 4.43. The mean ratio for the perpendicular-to-flow direction was 4.02, the standard deviation was 1.54, the minimum was 2.38, and the maximum was 7.97. In both rectangular and nonrectangular towers, the height-to-ratio indicates that overturning would be more likely in the direction parallel to the flow than in the perpendicular direction.

For each tower in the database, at least one location was identified as a critical section where failure was most likely to occur. The first critical section parameter to be examined is the clear height of the tower defined as the distance from the bottom of the critical section to the top of the tower. This is an important parameter in that the vertical dead load as well as the horizontal earthquake loads are directly dependent upon the mass of the structure above the critical section. Figure 8 shows the distribution of clear heights for all towers. The mean clear height was 93.79 ft, the standard deviation was 44.35 ft, the minimum was 19.07 ft, and the maximum was 209.00 ft.

$$t_{norm} = \frac{\sum_{i=1}^{n} t_i l_i}{\sum_{i=1}^{n} l_i} \qquad (1)$$

The next parameter to be examined is the normalized wall thickness, Equation 1. Most rectangular towers can be considered as shear-wall-type structures containing from two to six parallel shear walls in each direction. Often these parallel walls were of similar thickness and had a fairly uniform thickness along the length. However, many critical sections contained walls that were not this uniform. For the purpose of obtaining an average shear wall thickness at a given critical section in a given direction, the normalized wall thickness was calculated. For these rectangular towers, this parameter is defined as the thickness of each shear wall at a critical section in a given direction, multiplied by each wall length, and then summed and divided by the sum of the wall lengths. In this way, a single average wall thickness was developed for each critical section in each direction normalized by the length of the individual walls.

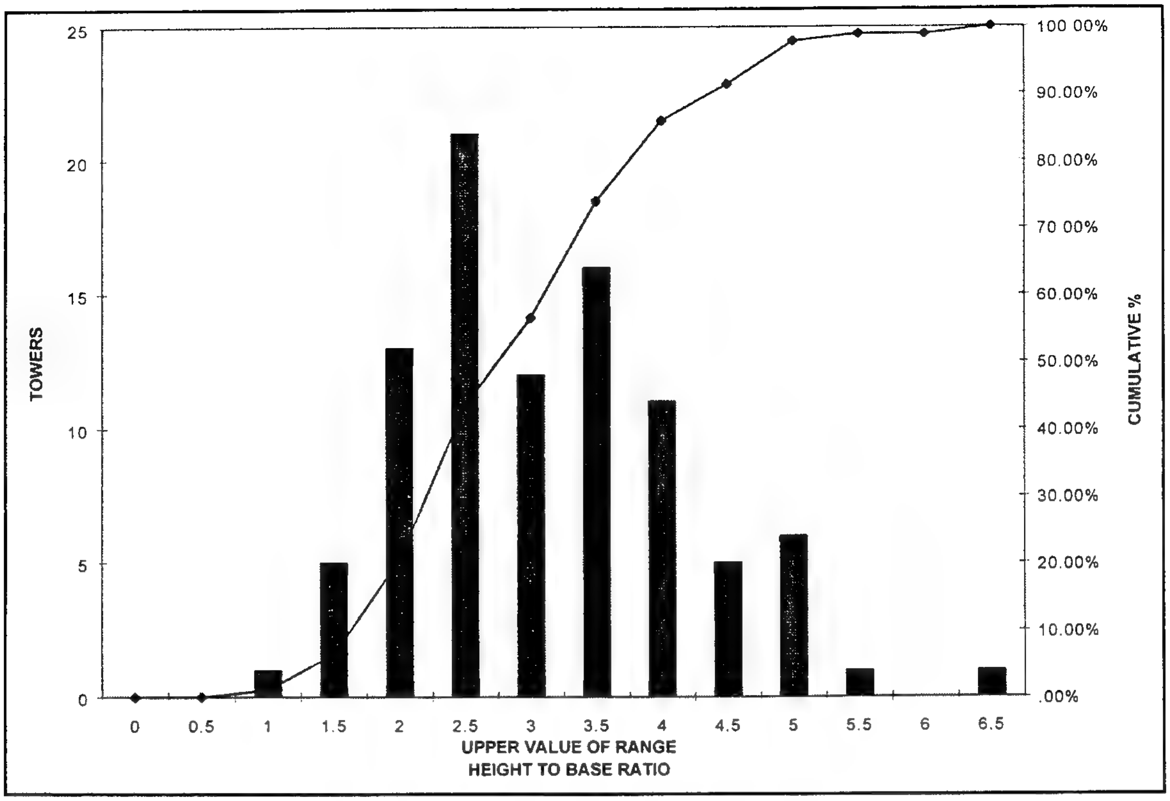

Figure 4. Distribution of rectangular towers by ratio of total height-to-base width

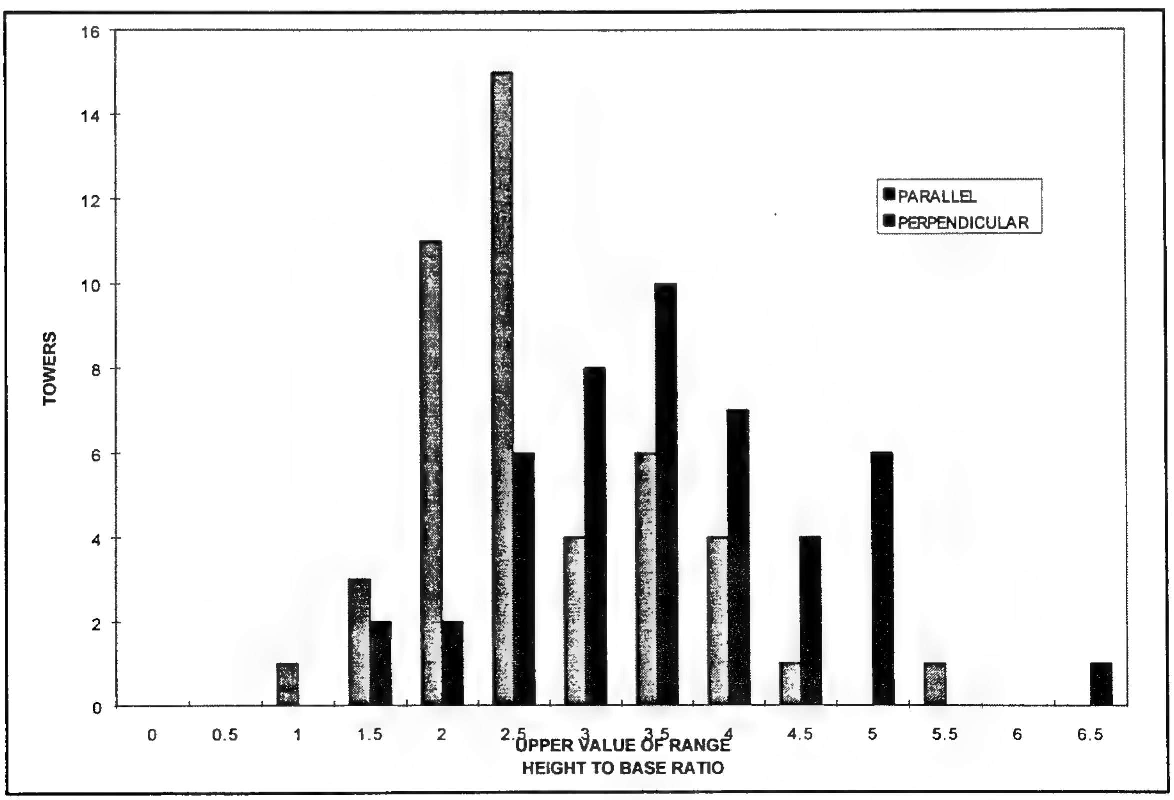

Figure 5. Distribution of rectangular towers by ratio of height-to-base width for parallel and perpendicular axis directions

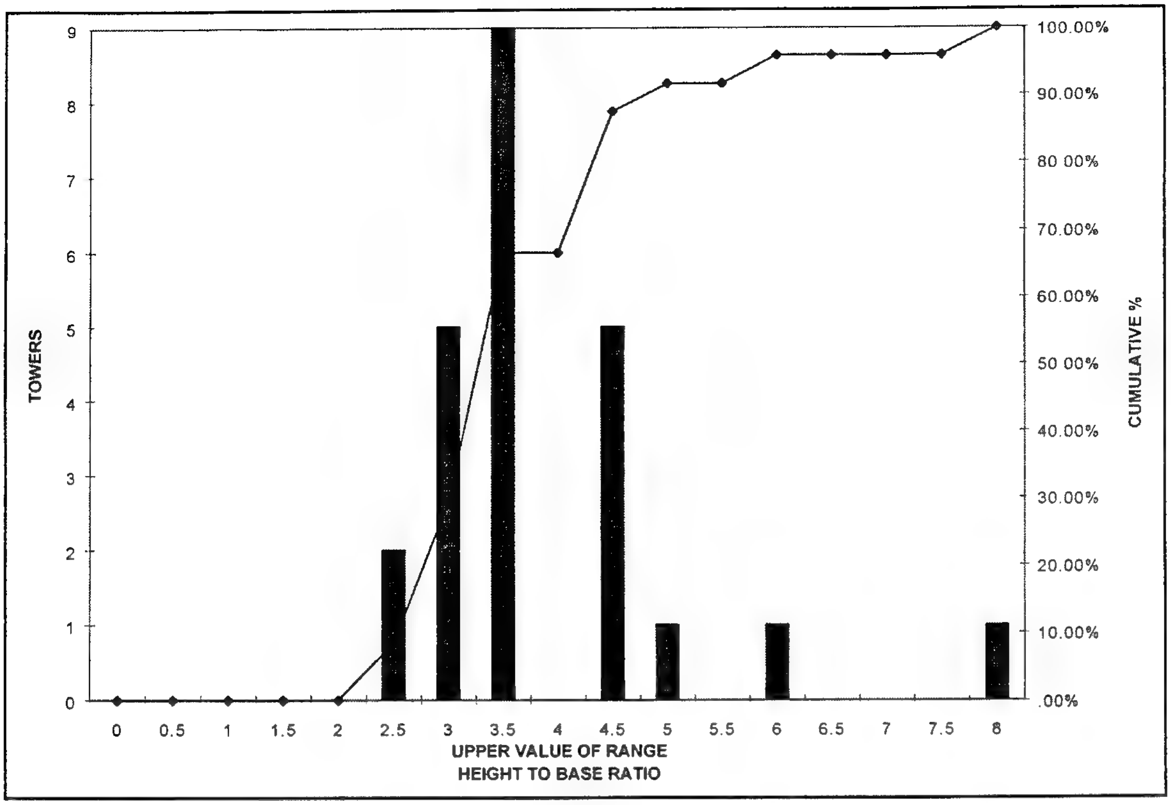

Figure 6. Distribution of nonrectangular towers by ratio of total height-to-base width

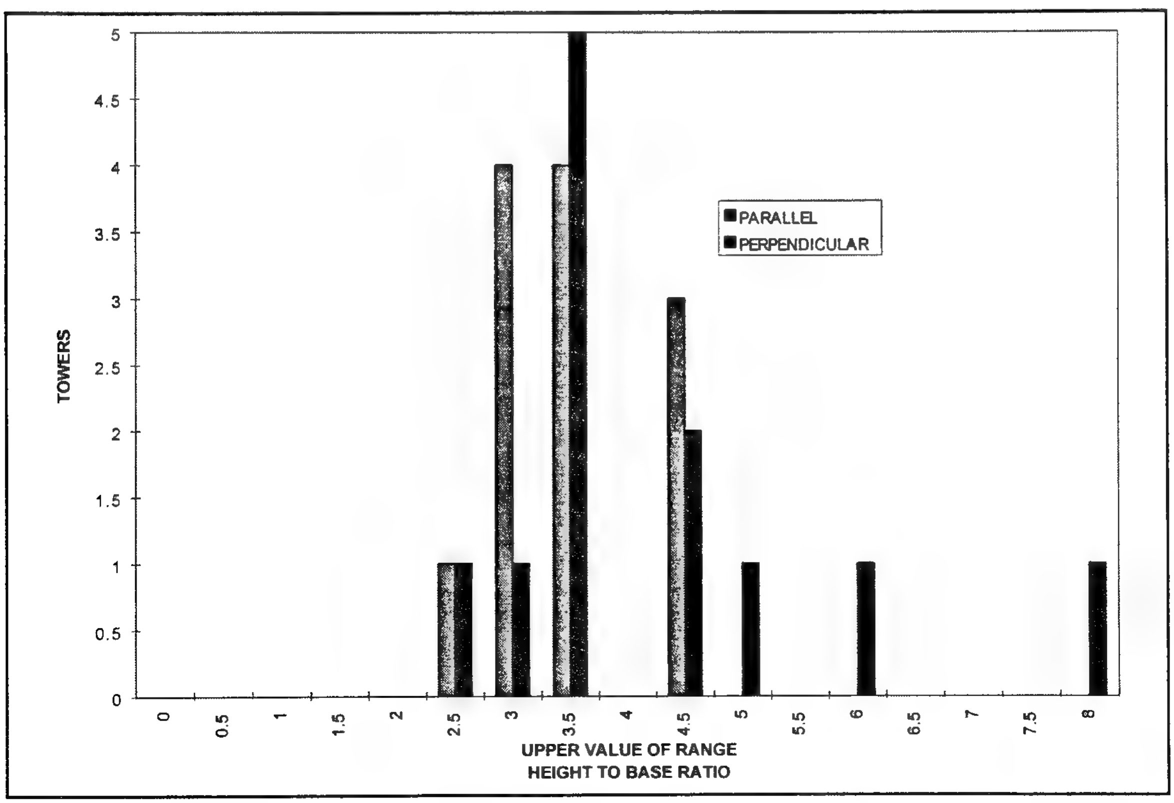

Figure 7. Distribution of nonrectangular towers by ratio of height-to-base width for parallel and perpendicular axis directions

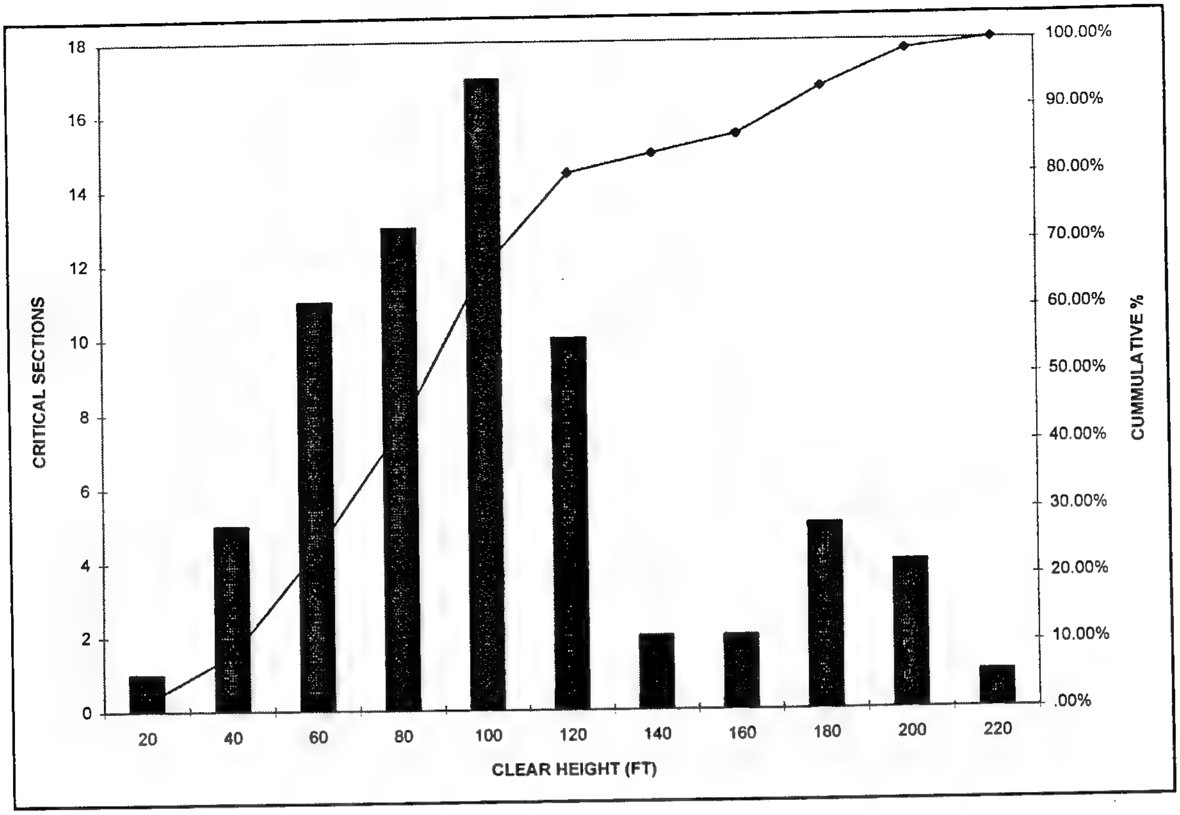

Figure 8. Distribution of critical sections by clear height above critical section

This information will be useful in the development of the shear wall testing and analysis program being planned. This is not intended to define the properties of the critical section itself as it does not indicate the number of walls in the section. Figure 9 shows the distribution of normalized wall thickness for rectangular towers. Figure 10 shows the distribution of normalized wall thickness for rectangular towers with both axis directions shown separately. The mean normalized thickness for the parallel-to-flow direction was 3.29 ft, the standard deviation was 2.11 ft, the minimum was 1.06 ft, and the maximum was 15.47 ft. The mean normalized wall thickness for the perpendicular-to-flow direction was 3.35 ft, the standard deviation was 2.06 ft, the minimum was 1.05 ft, and the maximum was 15.75 ft.

For all the nonrectangular towers included in this analysis, the critical sections were circular or octagonal and hence had an identifiable single actual wall thickness. Figure 11 shows the distribution of wall thickness for nonrectangular crossections. The mean wall thickness was 3.30 ft, the standard deviation was 1.43 ft, the minimum was 2.00 ft, and the maximum was 6.5 ft.

Much of the information and guidance available on the earthquake response of reinforced concrete shear wall structures have been developed for the analysis and design of buildings. In considering the response of rectangular intake towers as shear wall structures, it is important to compare the properties of the towers

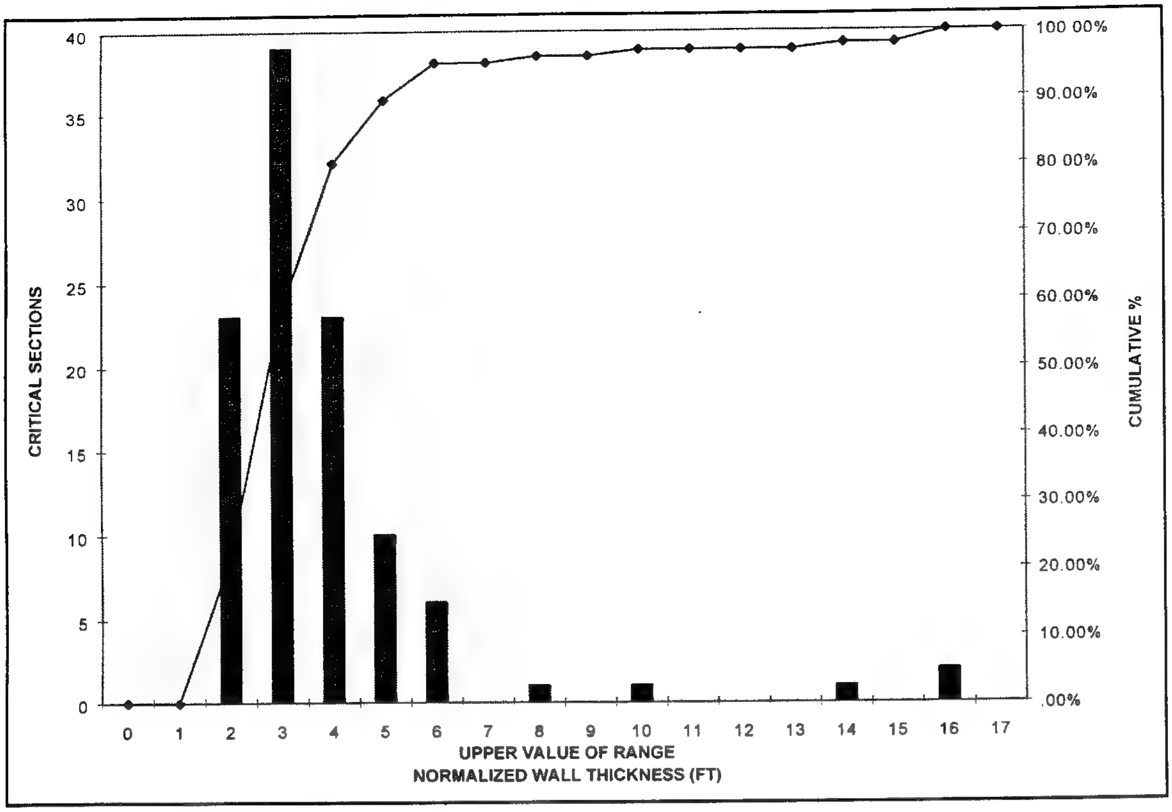

Figure 9. Distribution of rectangular tower critical sections by normalized wall thickness

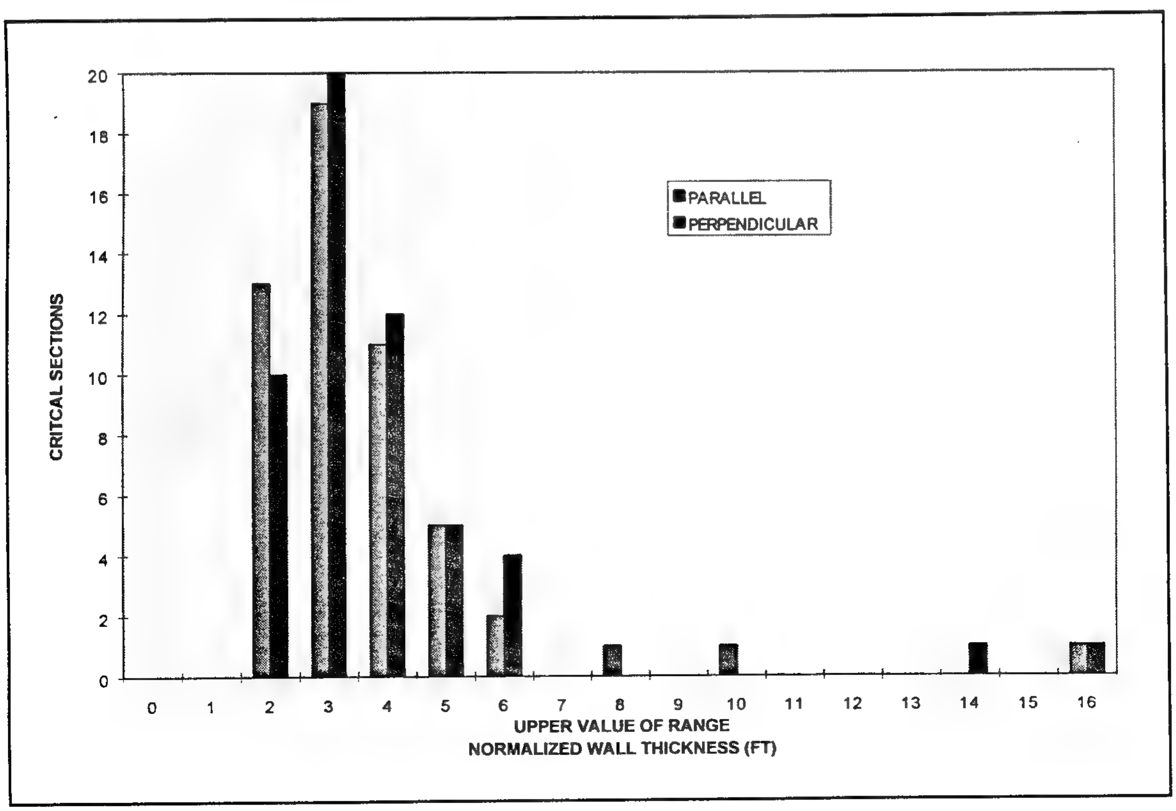

Figure 10. Distribution of rectangular tower critical sections by normalized wall thickness for parallel and perpendicular axis directions

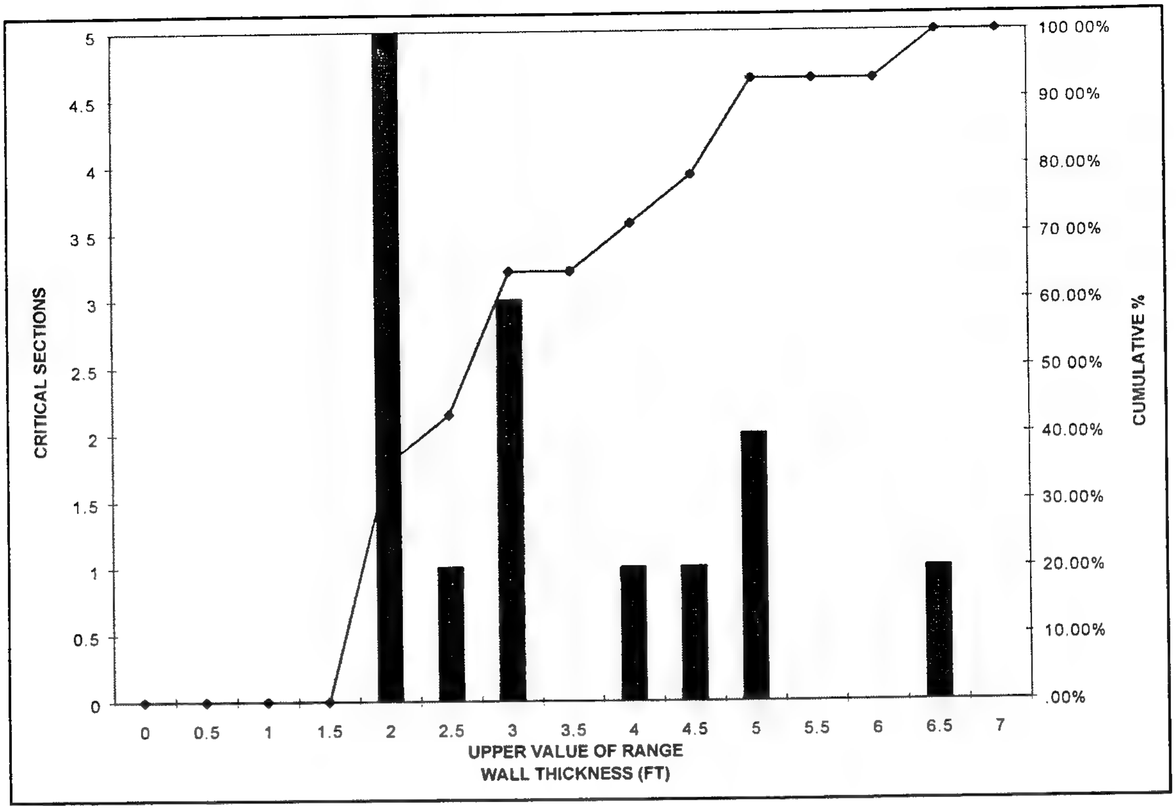

Figure 11. Distribution of nonrectangular tower critical sections by wall thickness

with shear wall buildings. The literature[1] contains a parameter called the wall area ratio that attempts to quantify the contribution of shear walls to the earthquake resistance of a building by calculating the ratio of the area of the shear walls in a given direction to the gross area of the building. This same reference indicates that for U.S. building construction, it is not unusual for this parameter to be as low as 0.005. At the same time, Chilean buildings with low steel percentages, large areas of shear walls, and good earthquake resistance had ratios that varied from 0.015 to 0.03. Figure 12 shows the distribution of wall area ratios for rectangular towers. Figure 13 shows the distribution of wall area ratios for rectangular towers with both axis directions shown separately. The mean wall area ratio for the parallel-to-flow direction was 0.242, the standard deviation was 0.101, the minimum was 0.113, and the maximum was 0.560. The mean wall area ratio for the perpendicular-to-flow direction was 0.252, the standard deviation was 0.098, the minimum was 0.083, and the maximum was 0.593. These numbers are about an order of magnitude higher than Chilean buildings and two orders of magnitude above U.S. buildings. This may or may not bode well for the earthquake resistance of intake towers, but it does point out that care should be taken in applying criteria or analysis techniques generated for buildings to intake towers.

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[1] Wood, S. L. (1991). "Performance of reinforced concrete buildings during the 1985 Chile earthquake: Implications for design of structural walls," *Earthquake Spectra*, EERI, 7(4).

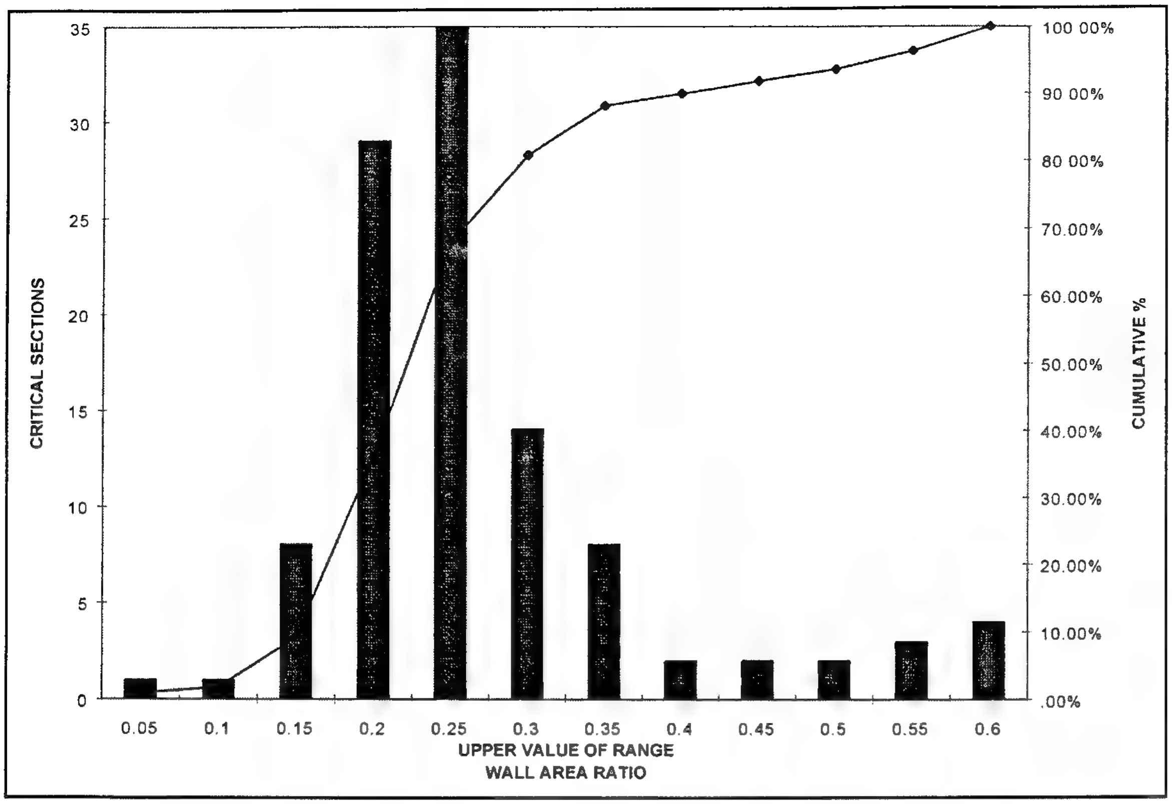

Figure 12. Distribution of rectangular tower critical sections by wall area to gross area ratio

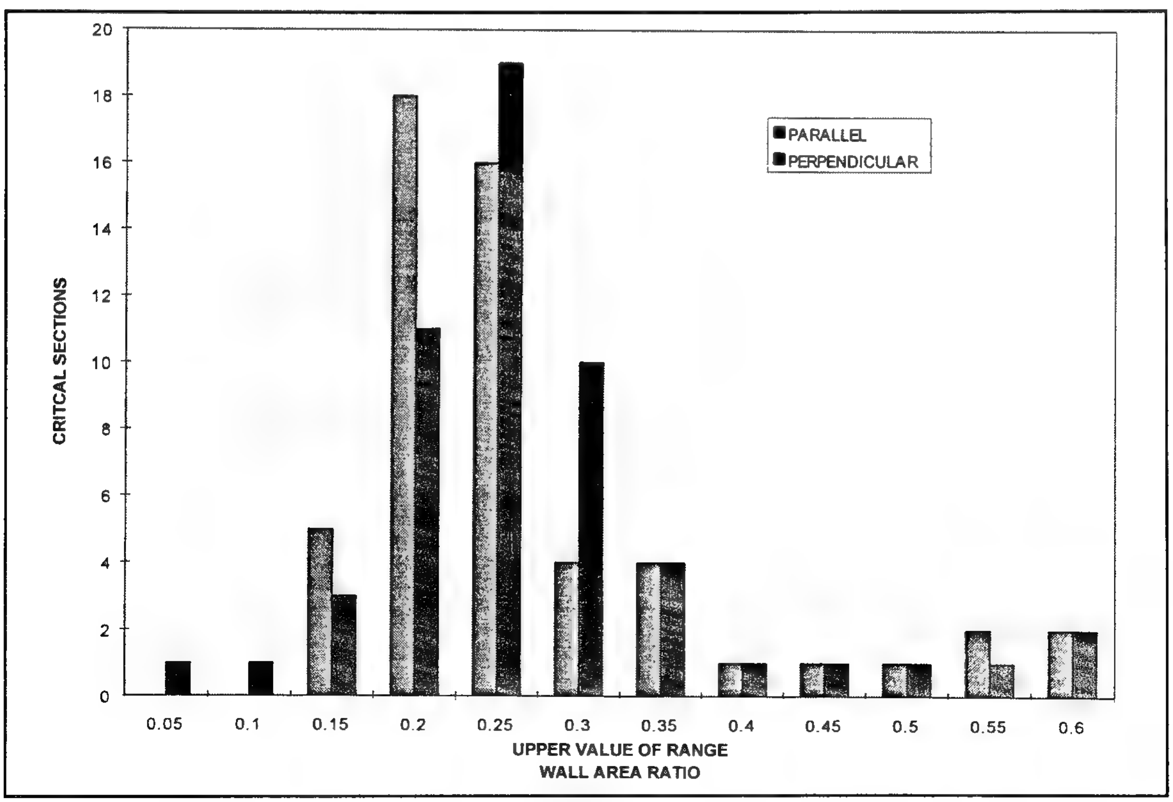

Figure 13. Distribution of rectangular tower critical sections by wall area to gross area ratio for parallel and perpendicular axis directions

The next group of parameters to be examined is the group of steel percentages. As with the shear wall thickness, the steel percentages for rectangular towers were normalized to account for nonuniformities in wall thickness, Equation 2.

$$\rho_{norm} = \frac{\sum_{i=1}^{n} \rho_1 A_i}{\sum_{i=1}^{n} A_i} \tag{2}$$

For the purpose of obtaining an average vertical or horizontal steel percentage at a given critical section in a given axis direction, the normalized steel percentage was calculated. For these rectangular towers, this parameter is defined as the vertical or horizontal steel percentage for a wall at a critical section in a given axis direction, multiplied by each wall area, and then summed and divided by the sum of the wall areas. In this way, a single average vertical and horizontal steel percentage was developed for each critical section in each axis direction normalized by the area of the individual walls. As with the normalized wall thickness, this information will be useful in the development of the shear wall testing and analysis program being planned. Again, this is not intended to define the properties of the critical section itself, since it does not indicate the number of walls in the section. Figure 14 shows the distribution of normalized vertical steel percentage for rectangular towers. Figure 15 shows the distribution of normalized vertical steel percentage for rectangular towers with both axis directions shown separately. The mean normalized vertical steel percentage for the parallel-to-flow direction was 0.280 percent, the standard deviation was 0.178 percent, the minimum was 0.075 percent, and the maximum was 1.040 percent. The mean normalized vertical steel percentage for the perpendicular-to-flow direction was 0.281 percent, the standard deviation was 0.166 percent, the minimum was 0.056 percent, and the maximum was 0.761 percent. Figure 16 shows the distribution of normalized horizontal steel percentage for rectangular towers. Figure 17 shows the distribution of normalized horizontal steel percentage for rectangular towers with both axis directions shown separately. The mean normalized horizontal steel percentage for the parallel-to-flow direction was 0.380 percent, the standard deviation was 0.251 percent, the minimum was 0.118 percent, and the maximum was 1.758 percent. The mean normalized horizontal steel percentage for the perpendicular-to-flow direction was 0.366 percent, the standard deviation was 0.161 percent, the minimum was 0.068 percent, and the maximum was 1.022 percent.

For all the nonrectangular towers included in this analysis, the critical sections were circular or octagonal and hence had identifiable actual vertical and horizontal steel percentages. Figure 18 shows the distribution of vertical steel percentage for nonrectangular cross sections. The mean vertical steel percentage for nonrectangular sections was 0.286 percent, the standard deviation was 0.155 percent, the minimum was 0.083 percent, and the maximum was 0.576 percent. Figure 19 shows the distribution of horizontal steel percentage for nonrectangular cross sections. The mean horizontal steel percentage for

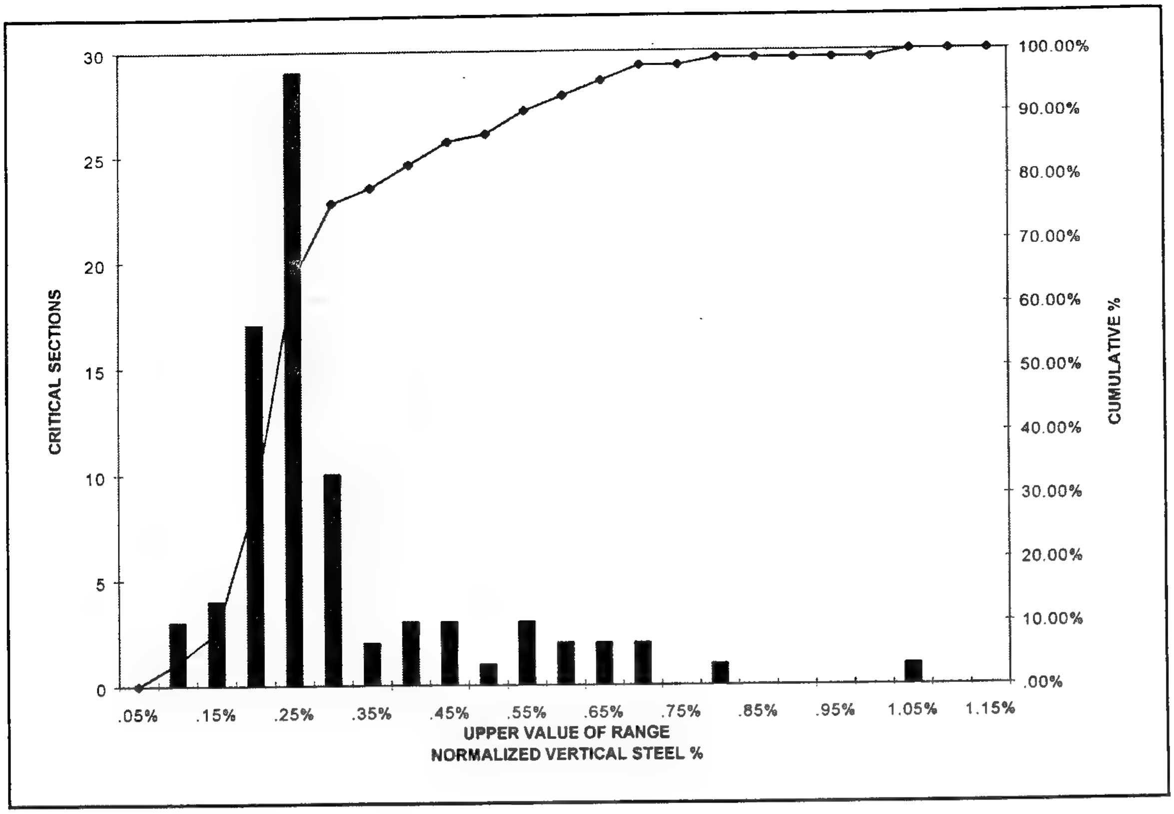

Figure 14. Distribution of rectangular tower critical sections by normalized vertical steel percentage of walls

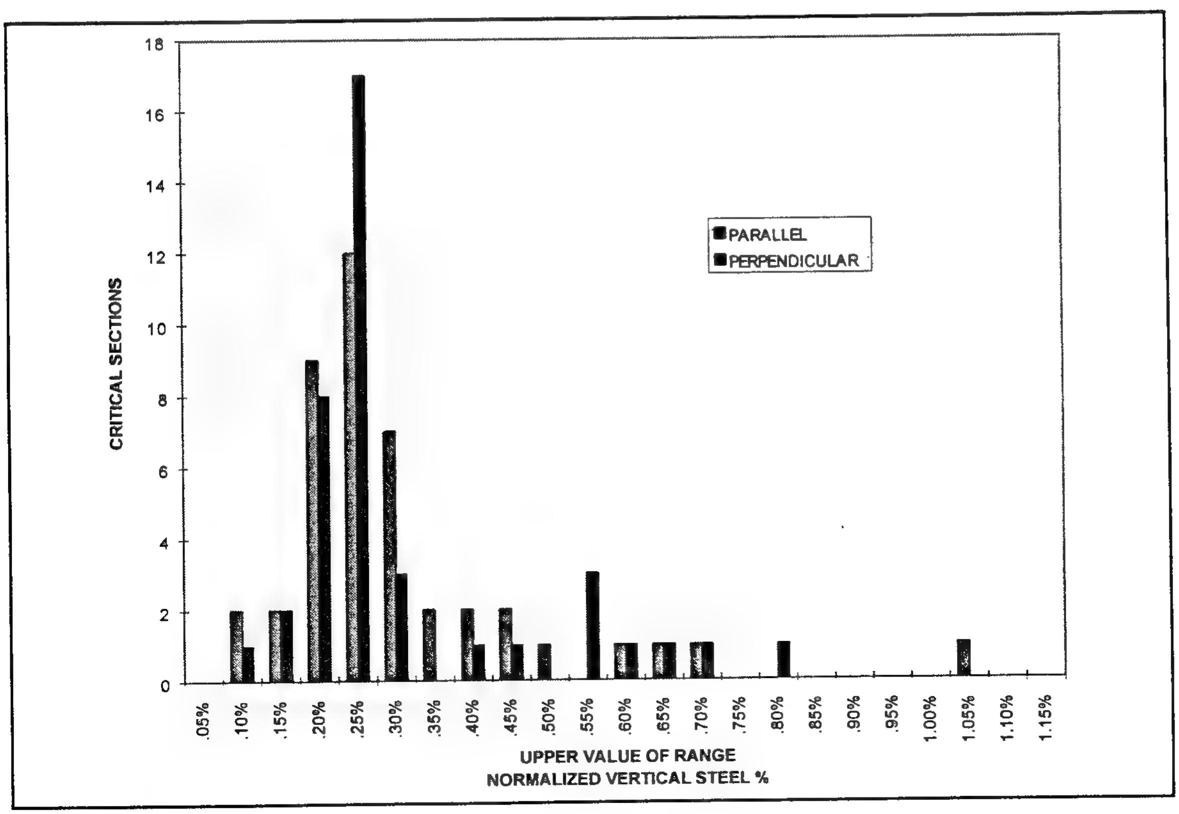

Figure 15. Distribution of rectangular tower critical sections by normalized vertical steel percentage of walls for parallel and perpendicular axis directions

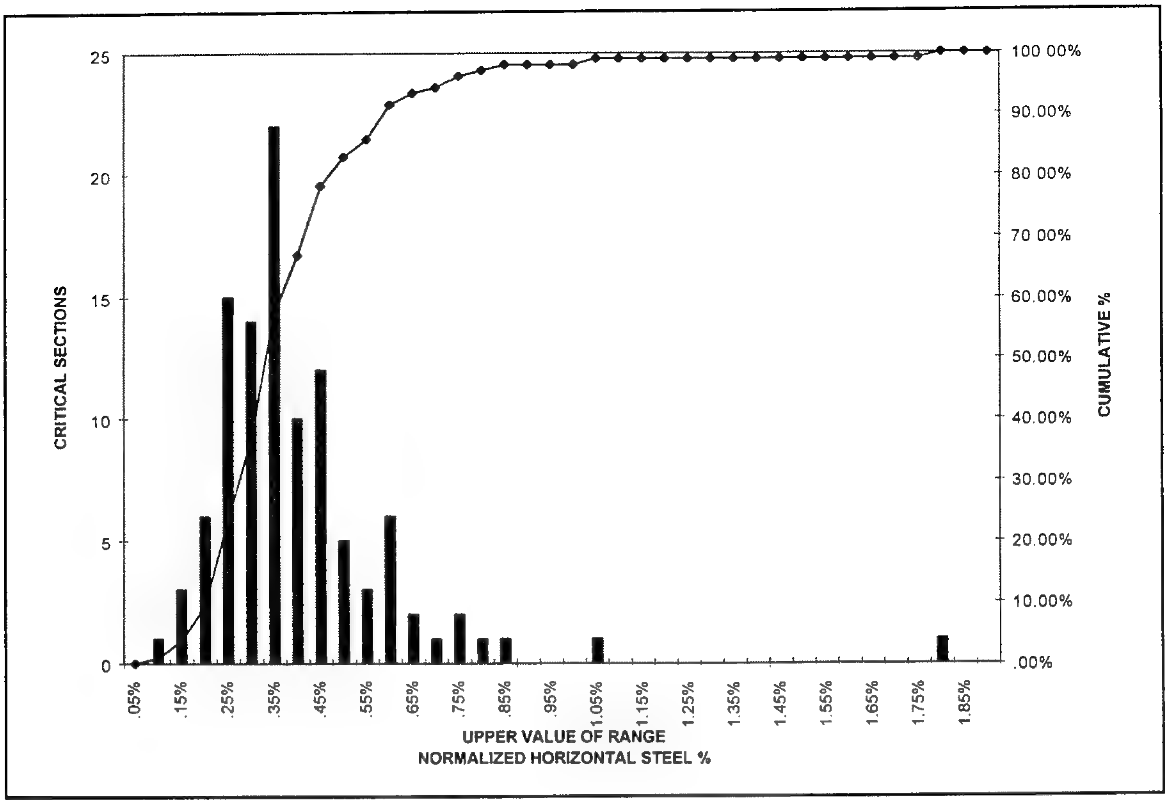

Figure 16. Distribution of rectangular tower critical sections by normalized horizontal steel percentage of walls

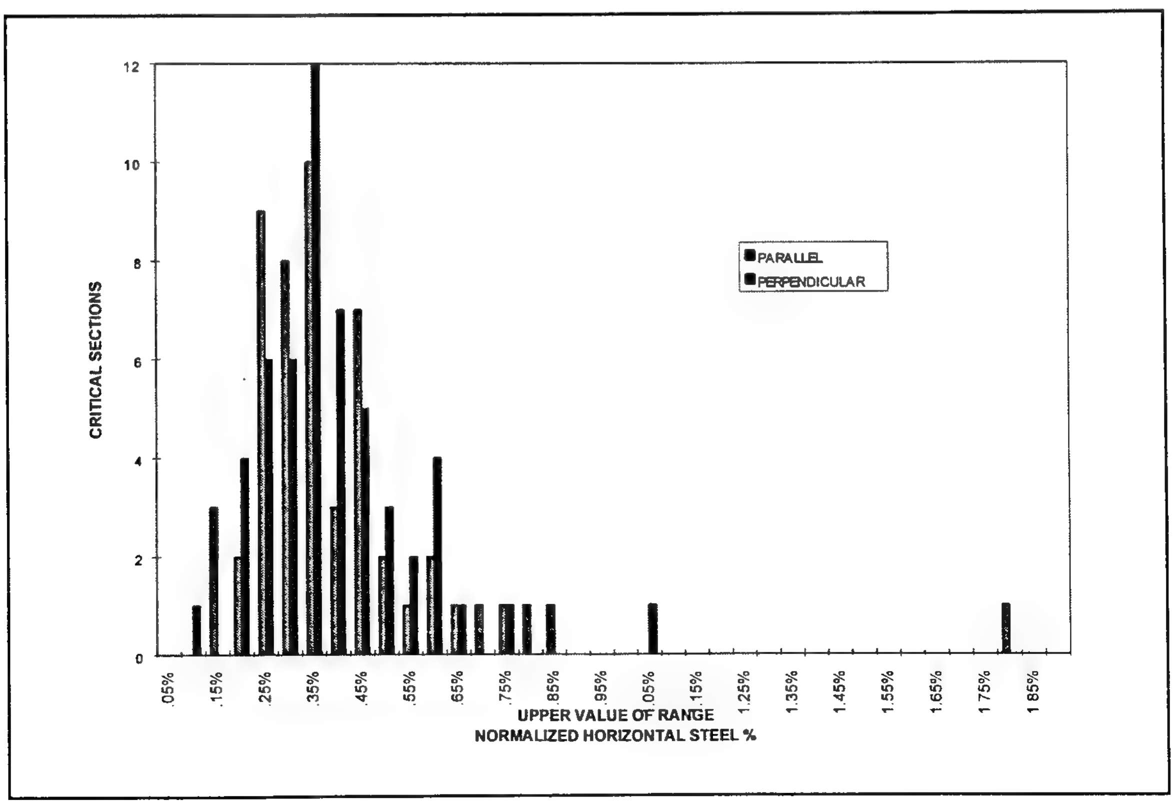

Figure 17. Distribution of rectangular tower critical sections by normalized horizontal steel percentage of walls for parallel and perpendicular axis directions

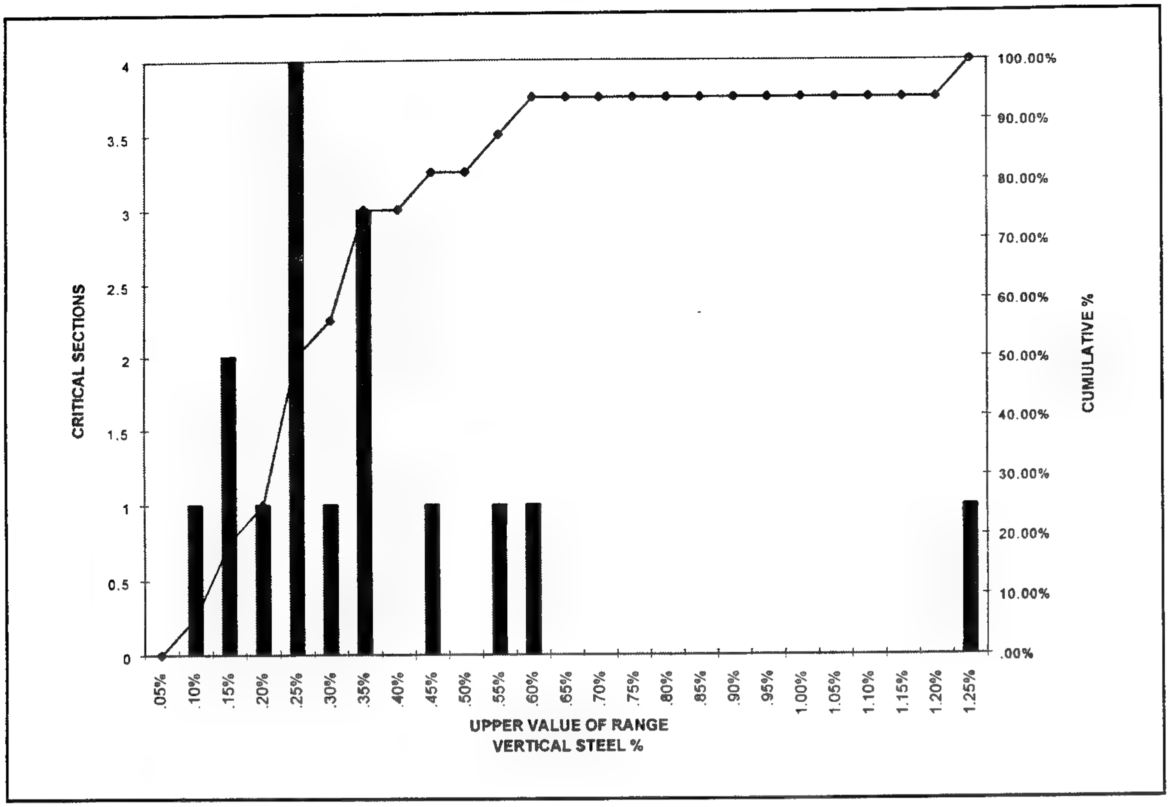

Figure 18. Distribution of nonrectangular tower critical sections by vertical steel percentage of walls

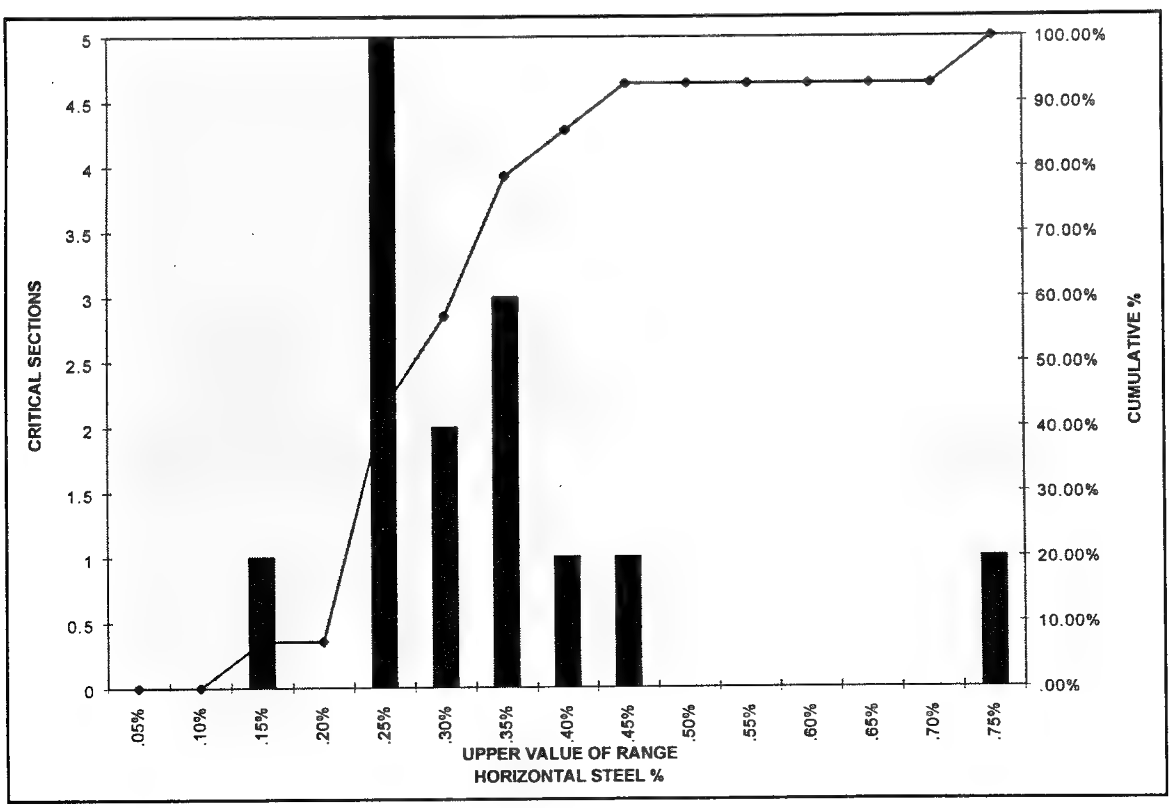

Figure 19. Distribution of nonrectangular tower critical sections by horizontal steel percentage of walls

nonrectangular sections the 0.303 percent, the standard deviation was 0.148 percent, the minimum was 0.104 percent, and the maximum was 0.732 percent.

The final parameter to be examined is the cracking moment of the critical section. The cracking moment[1] was calculated using Equation 3, where f_r is defined as the modulus of rupture calculated as per Equation 4, I_g the gross moment of inertia of the uncracked section without reinforcement, y_t the distance form the neutral axis to the extreme fiber of the concrete in tension.

$$M_{cr} = \frac{f_r I_g}{y_t} \tag{3}$$

$$f_r = 7.5\sqrt{f_c} \tag{4}$$

In Equation 2 the concrete strength (f'_c) is in psi and was assumed to be 3000 psi for all towers. The cracking moment can be considered as a measure of the initial stiffness of the critical section and is dependent only on the geometry of the section and concrete strength. Figure 20 shows the distribution of the cracking moment about the flow direction axis and the axis perpendicular to the flow direction. The mean cracking moment about the flow direction axis is 1.63 kip-ft, the standard deviation is 1.28 kip-ft, the minimum is 0.15 kip-ft, the maximum is 6.16 kip-ft. The mean cracking moment about the axis perpendicular to the flow direction axis is 1.62 kip-ft, the standard deviation is 1.28 kip-ft, the minimum is 0.13 kip-ft, and the maximum is 5.78 kip-ft.

[1] Wang, C. and Salmon, C. G. (1979). *Reinforced concrete design.* 3rd ed., Harper & Row, New York, NY.

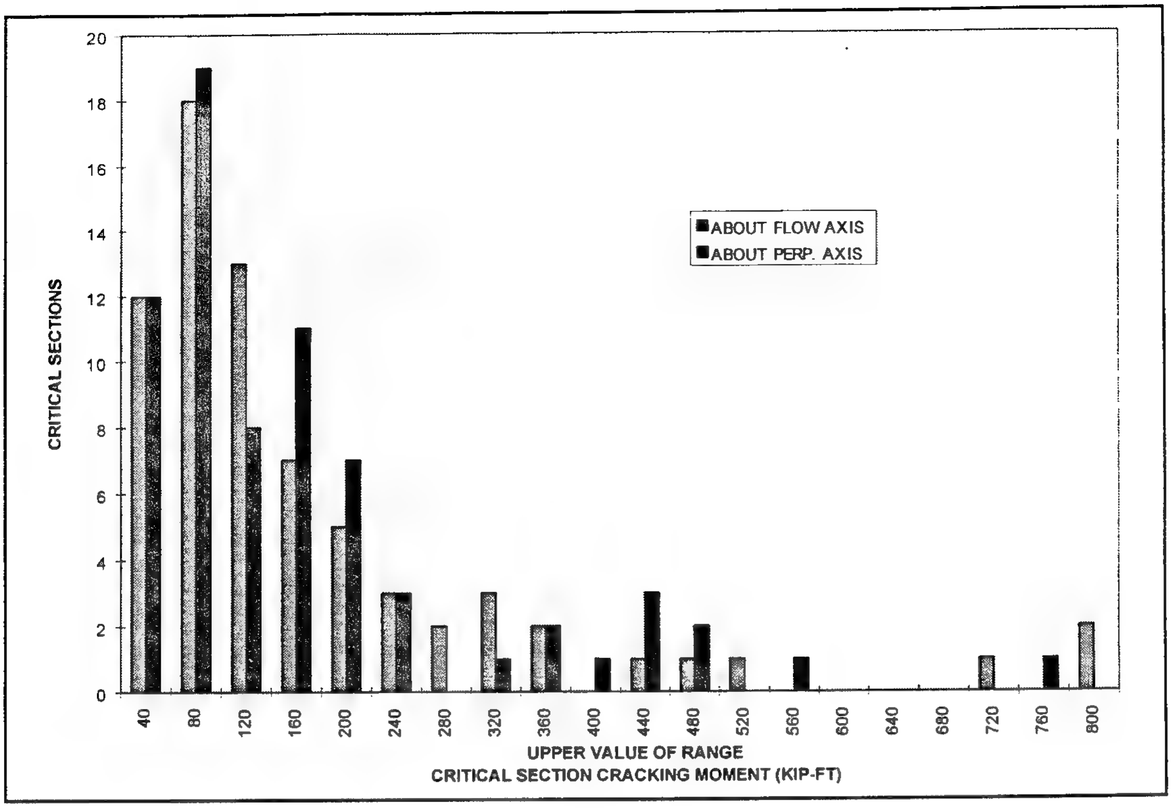

Figure 20. Distribution of all critical sections by moment required to initiate cracking of section

3 Conclusions and Recommendations

Conclusions

The specific objective of the tower inventory analysis was to quantify the distribution and variation of the structural characteristics of the USACE inventory of existing intake towers as relating to their earthquake location hazard. This was accomplished by the examination of the structural as-built drawings for 77 towers located in seismic zones 2 and above, the generation of a database containing 36 parameters for each of the towers, and a statistical analysis to summarize the distribution of these parameters. This information has already been useful in the preliminary planning of the intake tower shear wall component tests scheduled for FY 95 as well as subsequent substructure tests planned for FY 96.

As expected, the analysis was of assistance in the identification of possible failure mechanisms in that apparent critical sections could be identified for each tower. It was noteworthy that these critical sections were often at different elevations for the different major axis directions. Information contained in the database on wall thickness, material properties, reinforcing ratios, reinforcement details, and critical section details will be very important to future efforts in the quantification of the importance of different failure modes. The possibility of a rigid body overturning failure mode can now also be assessed in light of the distribution of the height-to-base ratio calculated for the tower population.

The ductility of intake towers as compared to reinforced concrete shear wall buildings can be evaluated in light of the wall area ratio. The wall area ratio is defined as the ratio of the area of the shear walls in a given direction to the gross area of the building and has been shown to be an important parameter in the determination of earthquake response. The wall area ratios of intake towers have been shown to be about an order of magnitude higher than Chilean buildings and two orders of magnitude above U.S. buildings. This may (or may not) bode well for the earthquake resistance of intake towers, but it also points out that care should be taken in applying criteria or analysis techniques generated for buildings to intake towers.

Recommendations

It is recommended that this database be maintained and expanded to include additional information as it becomes available. Specifically, more information is required on the material properties of the towers. The concrete and steel design strengths were more often than not missing from as-built structural design drawings. Even when this information was available it must be viewed as minimum design values that must be related to the actual in-place material properties with consideration of the age and condition of the structure.

As stated at the beginning of this report, the overall objective of this research program is to develop verified nonlinear analysis techniques for determining the ductility of existing intake towers under earthquake loads for all potential structural failure mechanisms, develop analysis procedures to account for this ductility, and to provide design and retrofit guidance for intake towers. This inventory analysis is a significant first step in the accomplishment of this objective.

Appendix A
Intake Tower Database/Spreadsheet

PROJECT	DISTRICT	YEAR BUILT	ZONE	TYPE	MAX. POOL (ft)	CONSERVATION POOL (ft)	MIN. POOL (ft)	TOTAL HEIGHT (ft)	BASE WDTH PAR wFLOW (ft)	BASE WDTH PERP wFLOW (ft)	BASE TO SERVICE BRIDGE (ft)	BASE TO CRIT SEC (ft)	BASE TO TOP OF COND (ft)	BASE TO AVG EMBDMNT (ft)	fy (ksi)	f'c (ksi)	CLR HEIGHT AT CRIT SEC (ft)	CRIT SEC WDTH PAR wFLOW (ft)	CRIT SEC WDTH PERP wFLOW (ft)	Ag at CRIT SEC (ft^2)	N.A. DIST. PAR. wFLOW (ft)	N.A. DIST. PERP. wFLOW (ft)	Ig ABT FLOW AXIS (ft^4)	Ig ABT AX PERP wFLOW (ft^4)
ENID	CELMK	50	2	R	67 5	29.5		131.71	53.5	47	92.5	36.5	28	24.5	40	4	95 21	34 5	32	1104	20 96	16	49983	67064
GRENADA	VICKSBURG	51	2	R	82.5	66	28	126.75	51.25	48.5	91	38	21.67	35	40	4	88.75	51.25	40.5	2075 625	29.3	20.22	105040	179020
	MS							126.75				48					78.75	35	40.5	1417 5	18 4	20.25	88598	70943
SARDIS		38	2	R	68	21	0	123.7	51	[illegible]	98	44	24	26	40	4	79.7	36.5	48	1752	18 38	24	214546	90495
REND LAKE	CELMS	72	2	R	49.2	34.5	21	53.5	24	23.5	53.5	13	11	13			40 5	14.0833	16.1667	227 67992	7.42	8 09	2464.7	1619
WAPPAPELLO	ST. LOUIS, MO	38	2	EMBEDDED																				
BLUE SPRINGS	CEMRK	82	2	R				53 67	59	28.5	53.5	30.5	20.5	4			23 17	28 25	28.5	805 125	13 92	16.02	23450	29094
CLINTON	KANSAS CITY	79	2	R	99.05	81.15	53.25	117.25	84.17	31.5	103.75	58.25	22.75	37	40	4	59	29 25	31	906.75	12.77	15.5	48956	43066
HILLSDALE	MO	77	2	R	[illegible]	54		100	52 33	28	80	61.5	27	30			38.5	52	28	1456	26.5	14	44789	118110
LONGVIEW		79	2	R	119.9	88		96	70 33	26	89	31	22.5	7			65	56 5	22	1243	26 85	10 95	26581	150330
MELVERN		67	2	R	118	81	78	150	62	33.5	123	[illegible]	23	35			64	35	33 5	1172.5	21 52	16.75	76725	80411
								150				32					118	61	33 5	2043 5	33 46	16.75	134930	268730
MILFORD		62	2	R	135.3	72.5	69 4	169 5	78	46.5	122	77.5	35	58			91	41 5	46 5	1929 75	20 75	23 12	208610	182990
PERRY		64	2	R	116.7	67	63 5	148 5	79	46 33	121.5	72.5	38 5				76	38	46.33	1760 54	18.34	23.16	177650	131480
POMONA		59	2	R	105.9	54.5	53	121.5	65.5	32.5	111 5	59.5	23 25	33.5			62	30 5	30.5	930 25	15.25	15.25	46699	46699
SMITHVILLE			2	R	100	74.2		115	62	36	107.5	86.2	30	51			28.8	32.75	25 8333	846.04058	15.31	12.92	23850	33876
TUTTLE CREEK		56	2	R	153.14	137.84		199.3	80	69	161	85	30	57			104.3	33	69	2277	15.84	34.5	44267	12035
ALMOND	CENAB	59	2	C	91.5			115.33	50	48.5	97	63	21.33	35			52.33			314 16	10	10	4637	4637
STILLWATER	BALTIMORE, M	59	2	R	67.6	7.6	3.6	92.27	45	14.67	72.6	55 6	13 25	55.6			36.67	11	11	121	6.38	5.5	900	927
GATHRIGHT	CENAO	70	2	R	257	159.5	131.5	262 04	80.5	57	262 04	75 25	49 5	44 5			186.79	55	43 666	2401.63	24 04	21 83	311230	509520
	NORFOLK,VA							262 04				192 5					69.54	35	38 333	1341.655	20.62	17 66	106930	92654
BELTZVILLE	CENAP		2	R/O	167.61	151.61	128.61	192.61									192.61			0				
	PHILADELPHIA																0			0				
BLUE MARSH	PA	72	2	R				114.26	62.75	29	99.09	62.09	18 09	17 09			52.17	30	29.25	877 5	14	14.625	22513	38817
F. E. WALTER			2	O	206	56		254.17	60 5	45	230	64 5	10.5	41			169 67			837.82	17 21	17.21	43148	43148
DEWEY	CEORH	45	2	R	107.75	82.75	41.75	141 83	44.56	43 29	114.75	47.75	19.47	41 75			94.08	37.79	43 29	1635.9291	18 774	21.674	221490	156050
FISHTRAP	HUNTINGTON	64	2	R	173.3	74	58	213	56 5	67 67	178.3	96	27	55.5	40	3	117.8	45.33	51	2311 83	25.7	25.5	307820	166870
FLANNAGAN	WV	60	2	R/O	201	126	90	268	60 5	59	236	59	34	33			209			372 49	16.52	16 52	34679	34679
N. FORK OF POUND		63	2	R	121	60	55	158 67	43	34	126	69	16.5	16 5			89 67	25	34	850	12.5	17	56984	33626
PAINT CREEK		67	2	R	113.62	53	41	153	51	45.25	119	58	20	58			95	30.75	35	1076 25	17.89	17.5	59600	32636
R. D. BAILEY		72	2	R/O	310	150	127	317.58	74	72	315	155	43				162.58			546.06	20.573	20 573	80416	80409
SUMMERSVILLE		65	2	SUBMERGED																				
YATESVILLE		88	2	R	107.5	60	35	120 08	34	38	120.08	23 5	18	16			96 58	33 5	38	1273	18 397	19	91795	77541
								120.08				65					55 08	20.5	37	758 5	10 25	18.5	44207	16633
BROOKVILLE	CEORL	65	2	R	150	115	88	217	53	55	184	55	21	42			162	32	37	1184	17.209	18.5	95709	68499
	LOUISVILLE							217				128					89	31	35	1085	16.395	17 5	61982	52997
CAGLES MILL	KY	49	2	C	112	45.5	44	161.25	49	38	138	56.5	20.5	33 9			104.75			380 13	11	11	6346	6346
C. M. HARDEN		56	2	R	88	60	38	132	39.75	31	110	48 33	14.5	33			83 67	21	28 5	598 5	10 5	14 25	24289	15386
								132				62					70	31 75	28 5	904 875	18 868	14 25	31852	25024
MONROE		60	2	R	62 5	44 5	21 5	106.94	34 79	45 25	80.5	49.5	18 5	28			57 44	29 3	33	966 9	18 234	16.5	36587	21055
NOLIN RIVER		58	2	R	143	103	63	192 5	50	42 25	164	72	23	48			120.5	31	38	1178	15 88	19	81680	56537
								192.5				106					86 5	31	38	1178	15 94	19	56359	41120
PATOKA		72	2	R	68	56	25	115	47	42.5	85	61	19 5	3.5			54	27	23 5	634 5	14 195	11.75	16539	22358
ROUGH RIVER		55	2	R	97.5	68.5	43 5	146 5	68.75	36	124 5	51.17	17 25	28 5			95 33	32 5	28 5	926 25	17 943	14 25	35320	35978
								146 5				69 5					77	21	28 5	598 5	10 5	14 25	26316	16736
TAYLORSVILLE		76	2	R	124	79	54	194	58	47.3	154	48.5	26	0	40		145 5	58	33	1914	27 477	16 511	108330	320840
								194				84					110	40 5	29 333	1187 9865	21 072	14 665	46761	85731
WEST FORK		50	2	R	49 5	22.5	22.5	103.5	44.3	29.8	83	32	14	22.5			71.5	18	25	450	9	12 5	12633	7348

INTAKE TOWERS

	WALLS PARALLEL TO FLOW											WALLS PARALLEL TO FLOW										
PROJECT	LENGTH 1 (ft)	THICKNESS 1 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO1 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO1 hor.	COVER1 I.F. (in)	COVER1 O.F. (in)	AREA OF SHEAR WALL1 (ft^2)	LENGTH2 (ft)	THICKNESS2 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO2 vert.	HOR STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO2 hor.	COVER2 I.F. (in)	COVER2 O.F. (in)	AREA OF SHEAR WALL2 (ft^2)
ENID	34.5	2	#6@18	#6@18	0.002037	#8@12	#8@12	0.005486	4	4	69	17.25	2	#6@18	#6@18	0.002037	#9@12	#8@12	0.0062153	4	4	34.5
GRENADA	35	2.27	#6@12	#6@12	0.0027914	#7@12	#7@12	0.0038065	4	4	79.45	35	2.27	#6@12	#6@12	0.0027914	#7@12	#7@12	0.0038065	4	4	79.45
	35	2	#5@12	#5@12	0.0021528	#6@12	#7@12	0.0036111	4	4	70	35	2	#5@12	#5@12	0.0021528	#6@12	#7@12	0.0036111	4	4	70
SARDIS	36.5	4.5	#6@24	#6@24	0.000679	#6@12	#6@12	0.001358	4	4	164.25	36.5	4.5	#6@24	#6@24	0.000679	#6@12	#6@12	0.001358	4	4	164.25
REND LAKE	14.083	1.0833	#8@12	#8@12	0.010128	#6@12	#6@12	0.005641	3	3	15.256114	14.083	1.0833	#8@12	#8@12	0.010128	#6@12	#6@12	0.005641	3	3	15.256114
WAPPAPELLO																						
BLUE SPRINGS	28.25	2.5	#6@12	#6@12	0.002444	#8@6	#11@12	0.008694	4	4	70.625	28.25	2.5	#6@12	#6@12	0.002444	#8@12	#11@12	0.0065	4	4	70.625
CLINTON	11	5.5	#6@12	#6@12	0.00111	#9@12	#9@12	0.002525	4	4	60.5	11	5.5	#6@12	#6@12	0.00111	#9@12	#9@12	0.002525	4	4	60.5
HILLSDALE	32.75	2.25	#9@12	#9@12	0.006173	#9@12	#9@12	0.006173	4	4	73.6875	32.75	2.25	#9@12	#9@12	0.006173	#9@12	#9@12	0.006173	4	4	73.6875
LONGVIEW	22.5	3	#6@12	#6@12	0.001746	#9@6	#9@12	0.002857	4	4	67.5	22.5	3	#6@12	#6@12	0.001746	#9@6	#9@12	0.002857	4	4	67.5
MELVERN	35	3	#7@12	#6@12	0.002407	#7@12	#7@12	0.00303	4	4	105	35	3	#7@12	#9@12	0.003704	#9@12	#7@12	0.003704	4	4	105
	35	5	#7@12	#9@12	0.002222	#9@12	#9@12	0.002778	4	4	175	35	5	#7@12	#9@12	0.002222	#9@12	#9@12	0.002778	4	4	175
MILFORD	41.5	4.5	#8@18	#8@18	0.001615	#9@12	#9@12	0.003086	4	4	186.75	41.5	4.5	#8@18	#8@18	0.001615	#9@12	#9@12	0.003086	4	4	186.75
PERRY	38	4	#8@18	#8@18	0.001817	#9@12	#9@12	0.003472	4	4	152	38	4	#8@18	#8@18	0.001817	#9@12	#9@12	0.003472	4	4	152
POMONA	30.5	3.5	#7@18	#7@18	0.001587	#9@18	#9@18	0.002646	4	4	106.75	30.5	3.5	#7@18	#7@18	0.001587	#9@18	#9@18	0.002646	4	4	106.75
SMITHVILLE	32.75	2	#9@12	#9@12	0.00694	#8@12	#8@12	0.005208	4	4	65.5	32.75	2	#9@12	#9@12	0.00694	#8@12	#8@12	0.005208	4	4	65.5
TUTTLE CREEK	33	3	#8@24	#8@24	0.001817	#8@24	#8@24	0.001817	4	4	99	33	3	#8@24	#8@24	0.001817	#8@24	#8@24	0.001817	4	4	99
ALMOND	20	2	52#6@12	62#6@12	0.0030779	#6@12	#6@12	0.0020528	2.5	2.5												0
STILLWATER	11	1.25	#6@12	#6@12	0.0048888	#6@9	#6@9	0.0065185	3	3	13.75	11	1.25	#6@12	#6@12	0.0048888	#6@9	#6@9	0.0065185	3	3	13.75
GATHRIGHT	23	43.666							4	4	1004.318	32	5.333	#9@12	#10@12	0.0029557	#6@12	#11@6	0.0046354	3	4	170.656
	35	2.6666	#8@12	#10@18	0.0042622	#8@12	#10@17	0.004392	3	4	93.331	35	2.6666	#8@12	#10@18	0.0042622	#8@12	#10@17	0.004392	3	4	93.331
BELTZVILLE											0											0
											0											0
BLUE MARSH	20.75	2.625	#6@12	#6@12	0.002328	#6@12	#8@12	0.003254	4	4	54.46875	20.75	2.625	#6@12	#6@12	0.002328	#6@12	#8@12	0.003254	4	4	54.46875
F. E. WALTER	34.42	4.9	50#6@18	69#6@18	0.0008327	#6@12	#6@18	0.0010391	3	3	168.658											0
DEWEY	37.79	8.26	#7@18	#7@18	0.0006726	#8@18	#8@18	0.0008856	4	4	312.1454	37.79	8.26	#7@18	#7@18	0.0006726	#8@18	#8@18	0.0008856	4	4	312.1454
FISHTRAP	45.333	5.333	#8@12	#8@12	0.0021944	#8@12	#9@12	0.0024861	2.5	2.5	241.76089	45.333	5.333	#8@12	#8@12	0.0021944	#8@12	#9@12	0.0024861	2.5	2.5	241.76089
FLANNAGAN	33.047	4.2656	80#9@12	104#9@12	0.00343	#9@12	#9@12	0.003256	4	4	140.96528											0
N. FORK OF POUN	25	4	#6@12	#6@12	0.001528	#7@12	#7@12	0.002083			100	25	4	#6@12	#6@12	0.001528	#7@12	#7@12	0.002083			100
PAINT CREEK	30.75	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037			92.25	30.75	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037			92.25
R. D. BAILEY	41.1458	5	96#8@12	128#8@12	0.0022505	#7@12	#9@12	0.0022222	2.5	2.5												0
SUMMERSVILLE																						
YATESVILLE	33.5	3	#8@12	#8@12	0.003657	#9@12	#8@12	0.0041435	2.5	3	100.5	33.5	3	#8@12	#8@12	0.003657	#9@12	#8@12	0.0041435	2.5	3	100.5
	20.5	2.5	#6@12	#6@12	0.002444	#7@12	#7@12	0.003333	2.5	2.5	51.25	20.5	2.5	#6@12	#6@12	0.002444	#7@12	#7@12	0.003333	2.5	2.5	51.25
BROOKVILLE	32	5	#7@12	#6@12	0.0014444	#6@12	#6@12	0.0012222	4	4	160	32	5	#7@12	#6@12	0.0014444	#6@12	#6@12	0.0012222	4	4	160
	31	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037	4	4	93	31	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037	4	4	93
CAGLES MILL	22	2	68#5@12	68#5@12	0.00233	#5@12	#5@12	0.002153	3	3												0
C. M HARDEN	21	2.5	#6@12	#6@12	0.002444	#6@12	#6@12	0.002444	2.5	2.5	52.5	21	2.5	#6@12	#6@12	0.002444	#6@12	#6@12	0.002444	2.5	2.5	52.5
	21	2.5	#6@12	#6@12	0.002444	#6@12	#6@12	0.002444	2.5	2.5	52.5	21	2.5	#6@12	#6@12	0.002444	#6@12	#6@12	0.002444	2.5	2.5	52.5
MONROE	21.16666	2	#6@12	#6@12	0.0030555	#8@12	#7@12	0.004826	2.5	2.5	42.33332	21.16666	2	#6@12	#6@12	0.0030555	#8@12	#7@12	0.004826	2.5	2.5	42.33332
NOLIN RIVER	31	2.875	#6@12	#6@12	0.0021256	#5@12	#5@12	0.0014976	2.5	2.5	89.125	31	2.875	#6@12	#6@12	0.0021256	#5@12	#5@12	0.0014976	2.5	2.5	89.125
	31	1.75	#5@12	#5@12	0.00246	#7@6	#7@6	0.009524	2.5	2.5	54.25	31	1.75	#5@12	#5@12	0.00246	#6@6	#6@6	0.006984	2.5	2.5	54.25
PATOKA	27	2	#5@12	#5@12	0.0021528	#7@12	#7@12	0.0041667	4	4	54	27	2	#5@12	#5@12	0.0021528	#7@12	#7@12	0.0041667	4	4	54
ROUGH RIVER	21	2.75	#6@12	#6@12	0.0022222	#6@12	#6@12	0.0022222	2.5	2.5	57.75	21	2.75	#6@12	#6@12	0.0022222	#6@12	#6@12	0.0022222	2.5	2.5	57.75
	21	2.75	#6@12	#6@12	0.0022222	#6@12	#6@12	0.0022222	2.5	2.5	57.75	21	2.75	#6@12	#6@12	0.0022222	#6@12	#6@12	0.0022222	2.5	2.5	57.75
TAYLORSVILLE	23	4.3333	#6@12	#6@12	0.00141	#9@12	#9@6	0.0048077			99.6659	23	4.3333	#6@12	#6@12	0.00141	#9@12	#9@6	0.0048077			99.6659
	40.5	2.5	#6@12	#6@12	0.0024444	#8@12	#8@12	0.0043889			101.25	40.5	2.5	#6@12	#6@12	0.0024444	#8@12	#8@12	0.0043889			101.25
WEST FORK	18	2	#7@14	#6@10.5	0.0035317	#6@12	#6@11	0.0033333	2.5	2.5	36	18	2	#7@14	#6@10.5	0.0035317	#6@12	#6@11	0.0033333	2.5	2.5	36

INTAKE TOWERS

WALLS PARALLEL TO FLOW

PROJECT	LENGTH3 (ft)	THICKNESS3 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO3 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO3 hor.	COVER3 I.F. (in)	COVER3 O.F. (in)	AREA OF SHEAR WALL3 (ft^2)
ENID	17.25	2	#6@18	#6@18	0.002037	#9@12	#8@12	0.0062153	4	4	34.5
GRENADA	35	2.27	#6@12	#6@12	0.0027914	#7@12	#7@12	0.0038065	4	4	79.45
	35	2	#5@12	#5@12	0.0021528	#7@12	#7@12	0.0041666	4	4	70
SARDIS	36.5	3	#6@24	#6@24	0.0010185	#6@12	[illegible]@12	0.002037	4	4	109.5
REND LAKE	14.08333	1	#8@12	#8@12	0.0109722	#6@12	[illegible]@12	0.006111	3	3	14.08333
WAPPAPELLO											
BLUE SPRINGS											
CLINTON	18.25	3	#9@12	#9@12	0.005556	#9@12	#9@12	0.005556	4	4	54.75
HILLSDALE	19.25	2	#8@12	#8@12	0.005451	#8@12	#9@12	0.006181	4	4	38.5
LONGVIEW	14.5	2.75	#6@12	#6@12	0.00222	#8@12	#11@12	0.005909	4	4	39.875
MELVERN											0
	26	5	#7@12	#7@12	0.001667	#9@12	#9@12	0.0027778	4	4	130
MILFORD											0
PERRY											0
POMONA											0
SMITHVILLE											0
TUTTLE CREEK	33	3	#8@24	#8@24	0.001817	#8@24	#8@24	0.001817	4	4	99
ALMOND											0
STILLWATER											0
GATHRIGHT	32	5.333	#9@12	#10@12	0.0028557	#6@12	#11@6	0.0046354	3	4	170.656
											0
BELTZVILLE											0
											0
BLUE MARSH	9.25	3	#6@12	#6@12	0.002037	#6@12	#8@12	0.0028472	4	4	27.75
F. E. WALTER											0
DEWEY	37.79	3.23	#7@18	#7@18	0.00172	#8@12	#8@12	0.003397	4	4	122.0617
FISHTRAP											0
FLANNAGAN											0
N. FORK OF POUN											0
PAINT CREEK	21.5	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037			64.5
R. D BAILEY											0
SUMMERSVILLE											
YATESVILLE	33.5	3	#8@12	#8@12	0.003657	#9@12	#9@12	0.0046296	2.5	2.5	100.5
											0
BROOKVILLE											0
											0
CAGLES MILL											0
C. M. HARDEN	10.75	2	#6@12	#6@12	0.003055	#6@12	#6@12	0.003055	2.5	2.5	21.5
											0
MONROE	8.14	1.5	#6@12	#6@12	0.004074	#6@12	#6@12	0.004074	2.5	2.5	12.21
NOLIN RIVER	31	3	#6@12	#6@12	0.002037	#5@12	#5@12	0.001435	2.5	2.5	93
	31	1.75	#5@12	#5@12	0.00246	#6@6	#6@6	0.006984	2.5	2.5	54.25
PATOKA	27	1.5	#5@12	#5@12	0.0028704	#6@12	#6@12	0.004074	4	4	40.5
ROUGH RIVER	11.5	2	#6@12	#6@12	0.0030555	#6@12	#6@12	0.0030555	2.5	2.5	23
											0
TAYLORSVILLE	23	3.5	#6@12	#6@12	0.001746	#8@6	#8@6	0.0062698			80.5
	22.5	2	#6@123	#6@12	0.0030556	#7@12	#7@12	0.0041667			45
WEST FORK											0

WALLS PARALLEL TO FLOW

PROJECT	LENGTH4 (ft)	THICKNESS4 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO4 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO4 hor.	COVER4 I F (in)	COVER4 O F. (in)	AREA OF SHEAR WALL4 (ft^2)
ENID	17.25	2	#6@18	#6@18	0.002037	#9@12	#8@12	0.0062153	4	4	34.5
GRENADA	35	2.27	#6@12	#6@12	0.0027914	#7@12	#7@12	0.0038065	4	4	79.45
	35	2	#5@12	#5@12	0.0021528	#7@12	#7@12	0.0041666	4	4	70
SARDIS	36.5	3	#6@24	#6@24	0.0010185	#6@12	#6@12	0.002037	4	4	109.5
REND LAKE											0
WAPPAPELLO											
BLUE SPRINGS											0
CLINTON	18.25	3	#9@12	#9@12	0.005556	#9@12	#9@12	0.005556	4	4	54.75
HILLSDALE	19.25	2	#8@12	#8@12	0.005451	#8@12	#9@12	0.006181	4	4	38.5
LONGVIEW	14.5	2.75	#6@12	#6@12	0.00222	#8@12	#11@12	0.005909	4	4	39.875
MELVERN											0
	26	5	#7@12	#7@12	0.001667	#9@12	#9@12	0.0027778	4	4	130
MILFORD											0
PERRY											0
POMONA											0
SMITHVILLE											0
TUTTLE CREEK	33	3	#8@24	#8@24	0.001817	#8@24	#8@24	0.001817	4	4	99
ALMOND											0
STILLWATER											0
GATHRIGHT											0
											0
BELTZVILLE											0
											0
BLUE MARSH	9.25	3	#6@12	#6@12	0.002037	#6@12	#8@12	0.0028472	4	4	27.75
F. E. WALTER											0
DEWEY	37.79	3.23	#7@18	#7@18	0.00172	#8@12	#8@12	0.003397	4	4	122.0617
FISHTRAP											0
FLANNAGAN											0
N. FORK OF POUN											0
PAINT CREEK											0
R. D BAILEY											0
SUMMERSVILLE											
YATESVILLE											0
											0
BROOKVILLE											0
											0
CAGLES MILL											0
C. M. HARDEN	10.75	2	#6@12	#6@12	0.003055	#6@12	#6@12	0.003055	2.5	2.5	21.5
											0
MONROE	8.14	1.5	#6@12	#6@12	0.004074	#6@12	#6@12	0.004074	2.5	2.5	12.21
NOLIN RIVER	31	3	#6@12	#6@12	0.002037	#5@12	#5@12	0.001435	2.5	2.5	93
	31	1.75	#5@12	#5@12	0.00246	#7@6	#7@6	0.009524	2.5	2.5	54.25
PATOKA											0
ROUGH RIVER	11.5	2	#6@12	#6@12	0.0030555	#6@12	#6@12	0.0030555	2.5	2.5	23
											0
TAYLORSVILLE	19	3.5	#6@12	#6@12	0.001746	#9@12	#9@12	0.003968			66.5
											0
WEST FORK											0

INTAKE TOWERS

PROJECT	WALLS PARALLEL TO FLOW											WALLS PARALLEL TO FLOW										
	LENGTH5 (ft)	THICKNESS5 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO5 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO5 hor.	COVER5 I.F. (in)	COVER5 O.F. (in)	AREA OF SHEAR WALLS (ft^2)	LENGTH6 (ft)	THICKNESS6 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO6 vert	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO6 hor.	COVER6 I.F (in)	COVER6 O.F (in)	AREA OF SHEAR WALL6 (ft^2)
ENID	17.25	2	#6@18	#6@18	0.002037	#9@12	#8@12	0.0062153	4	4	34.5											0
GRENADA	16 25	3.75	#8@12	#8@12	0.0029259	#7@12	#7@12	0.0022222	4	4	60.9375	16 25	3.75	#8@12	#8@12	0.0029259	#7@12	#7@12	0.0022222	4	4	60.9375
											0											0
SARDIS	36.5	3	#6@24	#6@24	0.0010185	#6@12	#6@12	0.002037	4	4	109.5											0
REND LAKE											0											
WAPPAPELLO																						0
BLUE SPRINGS											0											0
CLINTON	11	7.33	#6@12	#6@12	0.000834	#9@12	#9@12	0.001895	4	4	60.63											0
HILLSDALE											0											0
LONGVIEW	19.5	3.5	#6@12	#6@12	0.001746	#9@12	#10@12	0 004504	4	4	68 25											0
MELVERN											0											0
	6	5	#7@12	#7@12	0.001667	#9@12	#9@12	0 0027778	4	4	30											0
MILFORD											0											0
PERRY											0											0
POMONA											0											0
SMITHVILLE											0											0
TUTTLE CREEK	33	3	#8@24	#8@24	0.001817	#8@24	#8@24	0.001817	4	4	99											0
ALMOND											0											0
STILLWATER											0											0
GATHRIGHT											0											0
											0											0
BELTZVILLE											0											0
											0											0
BLUE MARSH	9.25	7	#6@12	#6@12	0.000873	#6@12	#6@12	0.000873	4	4	64.75											0
F. E. WALTER											0											0
DEWEY											0											0
FISHTRAP											0											0
FLANNAGAN											0											0
N. FORK OF POUN											0											0
PAINT CREEK											0											0
R. D. BAILEY																						
SUMMERSVILLE											0											0
YATESVILLE											0											0
											0											0
BROOKVILLE											0											0
											0											0
CAGLES MILL											0											0
C. M HARDEN											0											0
											0											0
MONROE											0											0
NOLIN RIVER											0											0
											0											0
PATOKA												11.5	2	#6@12	#6@12	0 0030555	#6@12	#6@12	0 0030555	2 5	2 5	23
ROUGH RIVER	11.5	2	#6@12	#6@12	0.0030555	#6@12	#6@12	0 0030555	2.5	2 5	23											0
											0	16	3.5	#6@12	#6@12	0 001746	#9@12	#9@12	0 003968			56
TAYLORSVILLE	19	3.5	#6@12	#6@12	0.001746	#9@12	#9@12	0 003968			66 5											0
											0											0
WEST FORK											0											

INTAKE TOWERS

PROJECT	WALLS PERPENDICULAR TO FLOW										
	LENGTH1 (ft)	THICKNESS1 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO1 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO1 hor.	COVER1 I.F. (in)	COVER1 O.F. (in)	AREA OF SHEAR WALLS1 (ft^2)
ENID	32	2	#6@18	#6@18	0.002037	#8@12	#6@12	0.004271	4	4	64
GRENADA	40.5	2.27	#6@12	#6@12	0.0027914	#7@12	#8@12	0.0044092	4	4	91.935
	40.5	2	#5@12	#5@12	0.0021528	#6@12	#6@12	0.0030555	4	4	81
SARDIS	48	3	#6@24	#6@24	0.0010185	#6@12	#6@12	0.002037	4	4	144
REND LAKE	16.166666	1.0833	#6@12	#6@12	0.005641	#6@12	#6@12	0.005641	3	3	17.513883
WAPPAPELLO											
BLUE SPRINGS	28.5	2.5	#6@12	#6@12	0.002444	#7@6	#11@12	0.007667	4	4	71.25
CLINTON	31	3	#9@12	#9@12	0.00463	#9@12	#11@12	0.005926	4	4	93
HILLSDALE	28	2.25	#8@12	#8&9@24	0.005154	#9@12	#9@12	0.006173	4	4	63
LONGVIEW	13	2.5	#6@12	#6@12	0.00244	#8@12	#9@12	0.004944	4	4	32.5
MELVERN	33.5	3	#6@12	#6@12	0.002037	#7@12	#7@12	0.00303	4	4	100.5
	33.5	4.5	#7@12	#9@12	0.002469	#9@12	#9@12	0.003086	4	4	150.75
MILFORD	46.25	5.25	#8@18	#8@18	0.001384	#9@6	#9@12	0.003968	4	4	242.8125
PERRY	46.33	4	#8@18	#8@18	0.001817	#9@12	#9@12	0.003472	4	4	185.32
POMONA	30.5	3.5	#7@18	#7@18	0.001587	#9@18	#9@18	0.002646	4	4	106.75
SMITHVILLE	32.75	2	#9@12	#9@12	0.00694	[illegible]@12	#8@12	0.005208	4	4	65.5
TUTTLE CREEK	69	3	#8@24	#8@24	0.001817	#8@24	#8@24	0.001817	4	4	207
ALMOND											0
STILLWATER	11	3.5	#9@9	#9@9	0.005291	#9@9	#9@9	0.005291	3	3	38.5
GATHRIGHT	43.6666	23							3	4	1004.3318
	38.33333	8.5	#9@12	#9@12	0.001634	#9@12	#9@12	0.001634	3	4	325.83331
BELTZVILLE											0
											0
BLUE MARSH	29.25	3	#6@12	#6@12	0.002037	#8@12	#8@12	0.0036574	4	4	87.75
F. E. WALTER											0
DEWEY	43.29	4.646	#7@16.5	#7@18	0.00125	#7@18	#7@18	0.001196	4	4	201.12534
FISHTRAP	51	5	#8@12	#8@12	0.0021944	#9@12	#10@12	0.0031528	2.5	2.5	255
FLANNAGAN											0
N. FORK OF POUN	34	4	#6@12	#6@12	0.001528	#9@6	#6@12	0.004236			136
PAINT CREEK	35	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037			105
R. D. BAILEY											0
SUMMERSVILLE											
YATESVILLE	38	5	#8@12	#8@12	0.0021944	#8@12	#8@12	0.0021944	2.5	3	190
	37	2.5	#6@12	#6@12	0.002444	#7@12	#7@12	0.003333	2.5	2.5	92.5
BROOKVILLE	37	5	#7@12	#7@12	0.0016667	#9@12	#7@12	0.0022222	4	4	185
	35	4	#6@12	#6@12	0.0015278	#9@12	#6@12	0.0025	4	4	140
CAGLES MILL											
C. M. HARDEN	28.5	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037	2.5	2.5	85.5
	28.5	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037	2.5	2.5	85.5
MONROE	33	2	#6@12	#6@12	0.0030556	#9@12	#7@12	0.0055556	2.5	2.5	66
NOLIN RIVER	38	2.5	#6@12	#6@12	0.0024444	#6@12	#6@12	0.0024444	2.5	2.5	95
	38	1.75	#5@12	#5@12	0.00246	#6@12	#6@12	0.00349	2.5	2.5	66.5
PATOKA	23.5	3	#6@12	#6@12	0.002037	#8@12	#8@12	0.003657	4	4	70.5
ROUGH RIVER	28.5	3.5	#6@12	#6@12	0.001746	#6@12	#6@12	0.001746	2.5	2.5	99.75
	28.5	3.5	#6@12	#6@12	0.001746	#6@12	#6@12	0.001746	2.5	2.5	99.75
TAYLORSVILLE	33	5	#6@12	#6@12	0.0012222	#11@12	#9@6	0.0049444			165
	29.333333	4	#6@12	#6@12	0.0015278	#8@6	#9@12	0.004479			117.33333
WEST FORK	25	2	#8@12	#8@12	0.005486	#6@12	#6@10.5	0.0032738	2.5	2.5	50

PROJECT	WALLS PERPENDICULAR TO FLOW										
	LENGTH2 (ft)	THICKNESS2 (ft)	VERT STL INSIDE FACE (in^2)	VERT. STEEL OUTSIDE FACE	RHO2 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO2 hor.	COVER2 I.F. (in)	COVER2 O.F. (in)	AREA OF SHEAR WALLS2 (ft^2)
ENID	32	2	#6@18	#6@18	0.002037	#8@12	#8@12	0.005486	4	4	64
GRENADA	40.5	2.27	#6@12	#6@12	0.0027914	#7@12	#8@12	0.0044092	4	4	91.935
	40.5	2	#5@12	#5@12	0.0021528	#7@12	#7@12	0.0041667	4	4	81
SARDIS	48	2.5	#6@24	#6@24	0.0012222	#6@12	#6@12	0.0024444	4	4	120
REND LAKE	16.166666	1	#6@12	#6@12	0.0061111	#6@12	#6@12	0.0061111	3	3	16.166666
WAPPAPELLO											
BLUE SPRINGS	28.5	3	#6@12	#6@12	0.002037	#8@12	#11@12	0.005417	4	4	85.5
CLINTON	31	2.5	#8@12	#8@13	0.004361	#9@12	#9@12	0.005556	4	4	77.5
HILLSDALE	28	2.25	#8@12	#8@13	0.004846	#8@12	#8@12	0.004846	4	4	63
LONGVIEW	22	2.5	#6@12	#6@12	0.00244	#8@12	#8@12	0.004361	4	4	55
MELVERN	33.5	3	#6@12	#6@12	0.002037	#7@12	#7@12	0.00303	4	4	100.5
	33.5	4.5	#7@12	#9@12	0.002469	#9@12	#9@12	0.003086	4	4	150.75
MILFORD	46.25	5.25	#8@18	#8@18	0.001384	#9@6	#9@12	0.003968	4	4	242.8125
PERRY	46.33	4.75	#8@18	#8@18	0.00153	#9@12	#9@12	0.002924	4	4	220.0675
POMONA	30.5	3.5	#7@18	#7@18	0.001587	#9@18	#9@18	0.002646	4	4	106.75
SMITHVILLE	32.75	2	#9@12	#9@12	0.00694	#8@12	#8@12	0.005208	4	4	65.5
TUTTLE CREEK	69	3	#8@24	#8@24	0.001817	#8@24	#8@24	0.001817	4	4	207
ALMOND											0
STILLWATER	11	1.25	#6@12	#6@12	0.0048888	#6@9	#6@9	0.0065185	3	3	13.75
GATHRIGHT	43.66666	8.5	#9@12	#11@12	0.0020915	#9@12	#11@9	0.0025163	3	4	371.16661
	38.333333	3	#9@12	#10@12	0.0052546	#9@12	#9@10	0.0050926	3	4	115
BELTZVILLE											0
											0
BLUE MARSH	29.25	2.5	#6@12	#6@12	0.0024444	#6@12	#6@12	0.0024444	4	4	73.125
F. E. WALTER											0
DEWEY	43.29	3.646	#7@16.5	#7@18	0.001593	#7@18	#7@18	0.001524	4	4	157.83534
FISHTRAP	51	5	#8@12	#8@12	0.0021944	#9@12	#10@12	0.0031528	2.5	2.5	255
FLANNAGAN											0
N. FORK OF POUN	34	4	#6@12	#6@12	0.001528	#7.5@6	#6@12	0.002413			136
PAINT CREEK	35	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037			105
R. D. BAILEY											0
SUMMERSVILLE											
YATESVILLE	38	3	#8@12	#8@12	0.003657	#9@12	#9@12	0.0046296	2.5	2.5	114
	37	2.5	#6@12	#6@12	0.002444	#7@12	#7@12	0.003333	2.5	2.5	92.5
BROOKVILLE	37	3	#7@12	#7@12	0.0027778	#6@12	#6@12	0.002037	4	4	111
	35	3	#6@12	#6@12	0.002037	#9@12	#6@12	0.0033333	4	4	105
CAGLES MILL											
C. M. HARDEN	28.5	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037	2.5	2.5	85.5
	28.5	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037	2.5	2.5	85.5
MONROE	33	3	#6@12	#6@12	0.002037	#7@12	#6@12	0.002407	2.5	2.5	99
NOLIN RIVER	38	2.5	#6@12	#6@12	0.0024444	#6@12	#6@12	0.0024444	2.5	2.5	95
	38	1.5	#5@12	#5@12	0.00287	#7@12	#7@12	0.0055555	2.5	2.5	57
PATOKA	23.5	2	#5@12	#5@12	0.0021528	#6@12	#7@12	0.0036111	4	4	47
ROUGH RIVER	28.5	3.5	#6@12	#6@12	0.001746	#6@12	#6@12	0.001746	2.5	2.5	99.75
	28.5	3.5	#6@12	#6@12	0.001746	#6@12	#6@12	0.001746	2.5	2.5	99.75
TAYLORSVILLE	31.333333	5	#6@12	#6@12	0.0012222	#8@6	#8@12	0.0032917			156.66667
	29.333333	2.5	#6@12	#6@12	0.0024444	#8@12	#8@12	0.0043889			73.333333
WEST FORK	25	2	#8@12	#8@12	0.005486	#6@12	#6@10.5	0.0032738	2.5	2.5	50

INTAKE TOWERS

	WALLS PERPENDICULAR TO FLOW											WALLS PERPENDICULAR TO FLOW										
PROJECT	LENGTH3 (ft)	THICKNESS3 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO3 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO3 hor.	COVER3 I.F. (in)	COVER3 O.F. (in)	AREA OF SHEAR WALLS3 (ft^2)	LENGTH4 (ft)	THICKNESS4 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO4 vert	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO4 hor.	COVER4 I.F (in)	COVER4 O.F (in)	AREA OF SHEAR WALLS4 (ft^2)
ENID	32	2	#6@18	#6@18	0.002037	#8@12	#9@12	0.0062153	4	4	64	32	2	#6@18	#6@18	0.002037	#9@12	#8@12	0.0062153	4	4	64
GRENADA	40.5	2.27	#6@12	#6@12	0.0027914	#8@12	#7@12	0.0044092	4	4	91.935	40.5	2.27	#6@12	#6@12	0.0027914	#7@12	#7@12	0.0038065	4	4	91.935
	40.5	2	#5@12	#5@12	0.0021528	#7@12	#6@12	0.0036111	4	4	81	40.5	2	#5@12	#5@12	0.0021528	#6@12	#7@12	0.0036111	4	4	81
SARDIS	48	2.5	#6@24	#6@24	0.0012222	#6@12	#6@12	0.0024444	4	4	120											0
REND LAKE	16.166666	1.0833	#6@12	#10@12	0.0109615	#6@12	#6@12	0.005641	3	3	17.513834											0
WAPPAPELLO																						
BLUE SPRINGS											0											0
CLINTON	31	2.5	#8@12	#8@13	0.004361	#9@12	#9@13	0.005556	4	4	77.5											0
HILLSDALE	28	2	#8@12	#8@13	0.005451	#8@12	#8@13	0.005451	4	4	56											0
LONGVIEW	22	2	#5@12	#5@12	0.002118	#8@12	#8@12	0.005451	4	4	44	22	3	#6@12	#6@12	0.002037	#9@12	#9@12	0.00463	4	4	66
MELVERN											0											0
											0											0
MILFORD											0											0
PERRY											0											0
POMONA											0											0
SMITHVILLE	32.75	2	#9@12	#9@12	0.00694	#8@12	#8@12	0.005208	4	4	65.5											0
TUTTLE CREEK											0											0
ALMOND											0											0
STILLWATER											0											0
GATHRIGHT											0											0
											0											0
BELTZVILLE											0											0
											0											0
BLUE MARSH	23	2.5	#6@12	#6@12	0.0024444	#6@12	#6@12	0.0024444	4	4	57.5											0
F. E WALTER											0											0
DEWEY	43.29	3	#7@16.5	#7@16.5	0.0020202	#7@18	#7@18	0.001852	4	4	129.87	43.29	3	#7@16.5	#7@16.5	0.0020202	#7@18	#7@18	0.001852	4	4	129.87
FISHTRAP											0											0
FLANNAGAN											0											0
N FORK OF POUN											0											0
PAINT CREEK											0											0
R. D BAILEY											0											0
SUMMERSVILLE																						
YATESVILLE	38	3	#8@12	#8@12	0.003657	#9@12	#8@12	0.0041435	2.5	3	114											0
											0											0
BROOKVILLE											0											0
											0											0
CAGLES MILL											0											0
C. M HARDEN											0											0
											0											0
MONROE											0											0
NOLIN RIVER	38	2.5	#6@12	#6@12	0.0024444	#6@12	#6@12	0.0024444	2.5	2.5	95											0
	38	1.75	#5@12	#5@12	0.00246	#6@12	#6@12	0.003611	2.5	2.5	66.5											0
PATOKA	23.5	1.5	#5@12	#5@12	0.0028704	#6@12	#6@12	0.004074	4	4	35.25											0
ROUGH RIVER											0											0
											0											0
TAYLORSVILLE	33	3	#6@12	#6@12	0.002037	#8@12	#9@12	0.0041435			99	33	2.5	#6@12	#6@12	0.0024444	#8@12	#8@12	0.0043889			82.5
	29.333333	2	#6@12	#6@12	0.0030556	#7@12	#7@12	0.0041667			58.666667											0
WEST FORK											0											0

PROJECT	DISTRICT	YEAR BUILT	ZONE	TYPE	MAX. POOL (ft)	CONSERVATION POOL (ft)	MIN. POOL (ft)	TOTAL HEIGHT (ft)	BASE WDTH PAR w/FLOW (ft)	BASE WDTH PERP w/FLOW (ft)	BASE TO SERVICE BRIDGE (ft)	BASE TO CRIT SEC (ft)	BASE TO TOP OF COND (ft)	BASE TO AVG EMBDMNT (ft)	fy (ksi)	fc (ksi)	CLR HEIGHT AT CRIT SEC (ft)	CRIT SEC WDTH PAR w/FLOW (ft)	CRIT SEC WDTH PERP w/FLOW (ft)	Ag at CRIT SEC (ft^2)	N.A. DIST. PAR. w/FLOW (ft)	N.A. DIST. PERP. w/FLOW (ft)	Ig ABT FLOW AXIS (ft^4)	Ig ABT AX PERP w/FLOW (ft^4)
ALAMO	CESPL	68	2	EMBEDDED																				
PAINTED ROCK	LOS ANGELES	59	2	R	179.1	143.8	12.8	212.11	77	67	188.02	113	33.18	32.8	40	3	99.11	18	21	378	9.125	10.5	12303	9298.5
WHITLOW	CA	59	2	EMBEDDED																				
BROKEN BOW	CESWT	64	2	R	114.7	74.5	34	120	65	60	120	45	34	40			75	54.2	52	2818.4	27.757	26	351350	411630
COUNCIL GROVE	TULSA	62	2	R	100.45	49.75	24.75	105.75	53.29	50	105.75	50.75	31.75	50.75			55	29.17	47.5	1385.575	15.09	26.718	104280	42732
PINE CREEK	OK	65	2	R	130	64.5	35	130	66.5	41	130	65	21.83	39			65	26	26	67[illegible]	13	13	18560	18560
WAURIKA		71	2	R	105	68.4	27	122	51.25	42.08	112	41.81	23.5	0	40	4	80.1[illegible]	36.75	42.08	1546.44	20.549	25.189	92388	88771
WISTER		45	2	R/COL	72.5	25.6		117.25	72	81	81.75	44	19	44			73.25	23.25	81	1883.25	11.625	40.5	746170	65000
W. KERR SCOTT	CESAW	63	2A	R	142.5	70	40	153.833	75	34	142.5	73	22.5	50	40		80.833	19	30	570	10.218	14.761	22353	11455
	WILMINGTON, NC																							
LUCKY PEAK	CENPW, WA	53	2B	R	244			267.83	86	55	267.83	84	39	24		3	183.83	71.33	55	3923.15	45.072	27.5	627510	683340
ARKABUTLA	CELMK, MS	40	3	R	85.3	69	40	136.5	57.85	59	95	71	30.5	35	40	4	65.5	41.5	45.5	1688.25	21	22.75	10892[illegible]	91371
APPLEGATE	CENPP	76	3	C/R	221			242.67	96.67	90	242.67	69	54	4			173.67	52.7	52	2740.4	27.441	26	599890	586590
BLUE RIVER	PORTLAND	65	3	C/R	253		76	263	87.5	33	263	91	44	91			172	38	38	1444	19	19	162260	1622[illegible]0
COUGAR	OR	59	3	C/R	284.75	275.75	117.75	317			290.75	169.75	17.75	169.75			147.25			3177.04	37.469	29	596760	596180
FALL CREEK		[illegible]	3	R				68.07	37.333	[illegible]	68.07	48	24				19.07	20.17	23	463.91	10.511	11.5	18188	14873
HILLS CREEK		57	3	C/R	140	91.5	11	164			145	65.5	21.5	27			98.5			19[illegible]2	32.416	22	208310	225790
LOST CREEK		72	3	C/R	252	192	131	271			271	85	36	80			186			0				
HOWARD HANSON	CENPS	58	3	R	194	110	39	216.05	41	47	197.05	53	25	109	40	3	163.05	45.5	47	2138.5	28.77	23.5	110980	93834
	SEATTLE							216.05				109					107.05	15.25	32.5	495.625	8.1423	20.168	26609	6658.3
MUD MOUNTN	WA		3	EMBEDDED																				
	CENPW																							
	WALLA WALLA																							
RIRIE	WA	72	3	C	128.5		32.5	157	56.08	46	135.5	39.5	20			4	117.5			530.93	13	13	15986	23852
CERRILOS	CESAJ	[illegible]	3	I/R	301.4	245	123	328							60									
	JACKSNVL,FL																							
BLACK BUTTE	CESPK	64	3	R	142.8	106.5	47.6	195.16	92.5	79.5	148	90.5	26	53			104.66	39	38.5	1501.5	19.55	19.505	112780	117110
BUCHANNAN	SACRAMENTO	72	3	C	206.5	185		211.5	63	61	211.5	90.5	29	25		3	121			660.52	14.5	14.5	15543.8	15543.8
ENGLEBRIGHT	CA	41	3	EMBEDDED																				
FARMINGTON		49	3	R	68	52.5	28	88.79	40	30	70	33	23.5	28.5			55.79	15	24	360	7.8125	12	11113	4487.7
HIDDEN		72	3	C	156.2	140	86	162.25	61.93	52	162.25	79.25	21	50		3	83			660.52	14.5	14.5	15543.8	15543.8
MARTIS CREEK		69	3	EMBEDDED																				
NEW HOGAN		60	3	EMBEDDED																				
SUCCESS		58	3	R		108.95	43.45	179.95	64	52	147.95	125.55	25.45	125.55			54.4	31	30	930	15.464	15.216	43835	46357
TERMINUS		61	3	C	230	179	55	271			235	81	16	145			190			804.25	16	16	21300	21300
FULLERTON	CESPL	41	3	R	41.5	33.5	4.5	64.27	42.5	23	51.25	35.[illegible]	12	21.8[illegible]			28.77	19.45	22.03	428.4835	9.7616	11.015	8198.4	7025.9
PRADO	LOS ANGELES	41	3	COL	100	87	4	127.67	91	95	110	44	20	3[illegible]			83.67	21.92	69.92	1532.6464				
SAN ANTONIO		56	3	EMBEDDED																				
SANTA FE		49	3	EMBEDDED																				
CARBON CANY.		61	4	R	96.7	78	6	116	40	40	102	33.4[illegible]	13	33	40	3	82.54	25.17	27.17	6[illegible]3.8689	12.8585	13.585	30045	26363
COYOTE VALLEY	CESPK	56	4	C/R	144.5	104.5	3	187	57.25	57.67	152	67.5	19	48	40	3	119.5			490.87	12.5	12.5	11320.8	11320.8
ISABELLA	SACRAMENTO	48	4	C	167	145.5		206.59				88.25		84			118.34			530.93	13	13	14578	14578
ISABELLA (AUX)		50	4	C	103	81.5		142.59	52	45	1[illegible].75	91	21	91			51.59			530.93	13	13	14578	1457[illegible]
WARM SPRINGS		78	4	EMBEDDED																				
AVERAGE		60.3			135.253	86.9567	48.9894	163.36965	58.4272	45.5927	138.38594	67.4261	24.43	43.0257	38.667	3.25	93.435104	32.9894	35.7067	1130.1002	17.3861	17.4028	103093.83	95842.011
std dev.		11.2			65.0291	53.5645	36.3428	63.350444	16.1618	16.5368	63.668605	32.0629	8.78698	32.6079	5.3452	0.52	46.939532	12.8242	12.7399	772.21152	7.31955	5.96593	152386.66	143986.88

INTAKE TOWERS

PROJECT	WALLS PARALLEL TO FLOW									
	LENGTH 1 (ft)	THICKNESS 1 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO1 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO1 hor.	COVER1 I.F. (in)	COVER1 O.F. (in)	AREA OF SHEAR WALL1 (ft^2)
ALAMO											
PAINTED ROCK	18	4	#10@12	#10@12	0.0044097	#8@12	#8@12	0.0027431	3	4	72
WHITLOW											
BROKEN BOW	54.2	4	#8@12	#8@12	0.002743	#8@12	#8@12	0.002743	3	3	216.8
COUNCIL GROVE											0
PINE CREEK											0
WAURIKA	19.75	6.75	#7@12	#9@12	0.0016461	#8@12	#9@12	0.0018416	4	4	133.3125
WISTER											0
W. KERR SCOTT	19	2	#6@12	#6@12	0.00356	#9@8	#10@5	0.015792	3	3	38
LUCKY PEAK	30	13.5	#8@12	#8@12	0.0008128	#8@6	#10@12	0.001466	4	4	405
ARKABUTLA	41.5	2.5	#6@24	#6@24	0.001222	#6@18	#7@12	0.0024815	4	4	103.75
APPLEGATE			71#10@12	#10@12	0.001284	#9@12			4	4	
BLUE RIVER			71#8@12	#11@8	0.0015212	#8@12	#10@12		4	4	
COUGAR	58	6.5	73#7@12	87#7@12	0.0012678	#9@12	#9@12	0.0021367	4	4	
FALL CREEK	20.17	4	#6@12	#6@12	0.0015278	#9@12	#9@12	0.0034722	4	4	80.68
HILLS CREEK	44	4	77#7@9	91#7@9	0.002785	#7@9	#7@9	0.0027777	4	4	
LOST CREEK											0
HOWARD HANSON	32	4	#6@12	#6@12	0.0015278	#8@11.5	#8@11.5	0.0028623	4	4	128
	15.25	2	#6@13	#6@13	0.0028205	#6@8	#5@11	0.0034659	2.5	2.5	30.5
MUD MOUNTN											
RIRIE	26	3	64#6@12	80#10@12	0.004157	#10@18	#10@18	0.0039198	3	4	
CERRILOS											
BLACK BUTTE	39	3.75	#11@12	#11@12	0.0057777	#7@6	#7@6	0.004444	3	3	146.25
BUCHANNAN	29	2	80#6@12	90#6@12	0.003062	#6@12	#8@12	0.004271	3	3	
ENGLEBRIGHT											
FARMINGTON	15	2	#6@12	#6@12	0.003055	#6@12	#6@12	0.0030555	3	3	30
HIDDEN	29	2	81#8@12	97#8@11	0.005756	#6@12	#6@12	0.0030555	4	4	
MARTIS CREEK											
NEW HOGAN											
SUCCESS	31	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037	3	3	93
TERMINUS	32	2	89#8@12	99#8@12	0.005472	#6@12	#6@12	0.0030555	3	3	
FULLERTON	19.45	1.52	#6@12	#6@12	0.0040205	#6@12	#6@12	0.0040205	3	3	29.564
PRADO											0
SAN ANTONIO											
SANTA FE											
CARBON CANY	25.17	3.58	#11@12	#11@12	0.006052	#11@9	#11@12	0.0070608	3	3	90.1086
COYOTE VALLEY	25	2.5	112#10@7	130#10@7	0.012077	#6@12	#6@12	0.0024444	3	3	
ISABELLA	26	3	64#6@12	80#6@12	0.0020298	#8@6	#8@6	0.0073148	3	3	
ISABELLA (AUX)	26	3	64#6@12	80#6@12	0.0020298	#7@12	#7@12	0.0027777	3	3	
WARM SPRINGS											
AVERAGE	28.554786	3.8989			0.0028442			0.0035286	3.333	3.386	102.86913
std dev.	9.4361713	5.2623			0.0020083			0.0023008	0.636	0.634	137.83596

PROJECT	WALLS PARALLEL TO FLOW									
	LENGTH2 (ft)	THICKNESS2 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO2 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO2 hor.	COVER2 I.F. (in)	COVER2 O.F. (in)	AREA OF SHEAR WALL2 (ft^2)
ALAMO											
PAINTED ROCK	18	4	#10@12	#10@12	0.0044097	#8@12	#8@12	0.0027431	3	4	72
WHITLOW											
BROKEN BOW	54.2	4	#8@12	#8@12	0.002743	#8@12	#8@12	0.002743	3	3	216.8
COUNCIL GROVE											0
PINE CREEK											0
WAURIKA	19.75	6.75	#7@12	#9@12	0.0016461	#8@12	#9@12	0.0018416	4	4	133.3125
WISTER											0
W. KERR SCOTT	19	2	#6@12	#6@12	0.00356	#9@8	#10@5	0.015792	3	3	38
LUCKY PEAK	30	13.5	#8@12	#8@12	0.0008128	#8@6	#10@12	0.001466	4	4	405
ARKABUTLA	41.5	2.5	#6@24	#6@24	0.001222	#6@18	#7@12	0.0024815	4	4	103.75
APPLEGATE											0
BLUE RIVER											0
COUGAR					0.000746				4	4	1060.78
FALL CREEK	20.17	4	#6@12	#6@12	0.0015278	#9@12	#9@12	0.0034722	4	4	80.68
HILLS CREEK					0.0120437				4	4	723.06
LOST CREEK											0
HOWARD HANSON	32	4	#6@12	#6@12	0.0015278	#8@11.5	#8@11.5	0.0028623	4	4	128
	15.25	2	#6@13	#6@13	0.0028205	#6@8	#5@11	0.0034659	2.5	2.5	30.5
MUD MOUNTN											
RIRIE	6.795	2	#6@15	#6@15	0.002444	#6@5	#6@5	0.0073333	4	4	13.59
CERRILOS											
BLACK BUTTE	39	3.75	#11@12	#11@12	0.0057777	#7@6	#7@6	0.004444	3	3	146.25
BUCHANNAN											0
ENGLEBRIGHT											
FARMINGTON	15	2	#6@12	#6@12	0.003055	#6@12	#6@12	0.0030555	3	3	30
HIDDEN											0
MARTIS CREEK											
NEW HOGAN											
SUCCESS	31	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037	3	3	93
TERMINUS											0
FULLERTON	19.45	1.52	#6@12	#6@12	0.0040205	#6@12	#6@12	0.0040205	3	3	29.564
PRADO											0
SAN ANTONIO											
SANTA FE											
CARBON CANY	25.17	3.58	#11@12	#11@12	0.006052	#11@9	#11@12	0.0070608	3	3	90.1086
COYOTE VALLEY											0
ISABELLA											0
ISABELLA (AUX)											0
WARM SPRINGS											
AVERAGE	27.175594	3.3205			0.0028486			0.0036833	3.358	3.425	92.212987
std dev.	9.6300406	1.9722			0.0021082			0.0023263	0.652	0.645	154.48055

INTAKE TOWERS

PROJECT	WALLS PARALLEL TO FLOW											WALLS PARALLEL TO FLOW										
	LENGTH3 (ft)	THICKNESS3 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO3 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO3 hor.	COVER3 I.F. (in)	COVER3 O.F. (in)	AREA OF SHEAR WALL3 (ft^2)	LENGTH4 (ft)	THICKNESS4 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO4 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO4 hor.	COVER4 I.F (in)	COVER4 O.F (in)	AREA OF SHEAR WALL4 (ft^2)
ALAMO																						
PAINTED ROCK	11.5	1.17	#4@12	#4@12	0.002381	#4@12	#4@12	0.002381	3	3	13.455	7.67	1	#4@12	#4@12	0 0027777	#4@12	#4@12	0.0027778	3	3	7.67
WHITLOW																						
BROKEN BOW	54.2	4	#8@12	#8@12	0.002743	#8@12	#8@12	0.002743	3	3	216.8											0
COUNCIL GROVE											0											0
PINE CREEK											0											0
WAURIKA	19.75	6	#8@12	#8@12	0.0018287	#8@12	#8@12	0.0018287	4	4	118.5	17	3.25	#9@12	#9@12	0.0042735	#9@12	#9@12	0.0042735	4	4	55.25
WISTER											0											0
W. KERR SCOTT	19	2	#6@12	#6@12	0.00356	#10@5	#10@5	0.021167	3	3	38											0
LUCKY PEAK	30	8	#8@12	#8@12	0.0013715	#8@6	#8@6	0.002743	4	4	240	41 33	4.75	#8@12	#8@12	0.00231	#8@6	#10@12	0.003713	4	4	196.3175
ARKABUTLA	41.5	2.5	#6@24	#6@24	0.0012222	#7@12	#7@12	0 0033333	4	4	103.75	41.5	2 5	#6@24	#6@24	0.0012222	#7@12	#7@12	0.0033333	4	4	103.75
APPLEGATE											0											0
BLUE RIVER											0											0
COUGAR											0											0
FALL CREEK	20.17	4	#6@12	#6@12	0.0015278	#9@12	#9@12	0.0034722	4	4	80 68											0
HILLS CREEK											0											0
LOST CREEK											0											0
HOWARD HANSON	16	3.5	#8@13	#8@13	0 0026938	#8@11.5	#8@11 5	0.0032714	4	4	56	16	3 5	#8@13	#8@13	0.0026938	#8@11.5	#8@11 5	0 0032714	4	4	56
	15.25	1	#4@13	#4@13	0 0025641	#5@11	#5@11	0.004697	2.5	2.5	15.25	15 25	1	#4@13	#4@13	0.0025641	#5@11	#5@11	0.004697	2.5	2 5	15 25
MUD MOUNTN																						
RIRIE	6 795	2	#6@15	#6@15	0 002444	#6@5	#6@5	0 0073333	4	4	13 59	4 75	4.5	#6@15	#6@15	0.001086	#6@15	#6@15	0 001086	4	4	21 375
CERRILOS																						
BLACK BUTTE	39	1.5	#10@18	#10@18	0.0078395	#5@14	#5@14	0 00246	3	3	58.5											0
BUCHANNAN											0											0
ENGLEBRIGHT																						
FARMINGTON											0											0
HIDDEN											0											0
MARTIS CREEK																						
NEW HOGAN																						
SUCCESS	31	2	#6@12	#6@12	0.0030555	#6@12	#6@12	0 0030555	3	3	62											0
TERMINUS											0											0
FULLERTON											0											0
PRADO											0											0
SAN ANTONIO																						
SANTA FE																						
CARBON CANY.																						
COYOTE VALLEY											0											0
ISABELLA											0											0
ISABELLA (AUX)											0											0
WARM SPRINGS																						
AVERAGE	23 664676	2 7362			0 0028854			0 0042701	3 348	3 379	33 888147	21.4672	2 62			0 0024809			0 003719	3 417	3 417	20 150779
std dev	11 127123	1 4782			0 0019358			0 0033215	0.652	0.654	52.389597	11.717174	1.0596			0 0012065			0 0018381	0 679	0 679	39 414173

INTAKE TOWERS

PROJECT	WALLS PARALLEL TO FLOW										
	LENGTH5 (ft)	THICKNESS5 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO5 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO5 hor.	COVER5 I.F. (in)	COVER5 O.F. (in)	AREA OF SHEAR WALLS5 (ft^2)
ALAMO											
PAINTED ROCK	7.67	1	#4@12	#4@12	0.0027777	#4@12	#4@12	0.0027778	3	3	7.67
WHITLOW											
BROKEN BOW											0
COUNCIL GROVE											0
PINE CREEK											0
WAURIKA	17	3.25	#9@12	#9@12	0.0042735	#9@12	#9@12	0.0042735	4	4	55.25
WISTER											0
W. KERR SCOTT											0
LUCKY PEAK	41.33	4.75	#8@12	#8@12	0.00231	#8@6	#10@12	0.003713	4	4	196.3175
ARKABUTLA											0
APPLEGATE											0
BLUE RIVER											0
COUGAR											0
FALL CREEK											0
HILLS CREEK											0
LOST CREEK											0
HOWARD HANSON	16	1.5	#5@13	#5@13	0.0026496	#5@11.5	#5@11.5	0.002995	4	4	24
											0
MUD MOUNTN											
RIRIE											0
CERRILOS											
BLACK BUTTE											0
BUCHANNAN											0
ENGLEBRIGHT											
FARMINGTON											0
HIDDEN											0
MARTIS CREEK											
NEW HOGAN											
SUCCESS											0
TERMINUS											0
FULLERTON											0
PRADO											0
SAN ANTONIO											
SANTA FE											
CARBON CANY.											
COYOTE VALLEY											0
ISABELLA											0
ISABELLA (AUX)											0
WARM SPRINGS											
AVERAGE	17.416667	3.372			0.001982			0.0028749	3.536	3.536	12.109276
std. dev.	10.869236	1.8796			0.0009574			0.0013688	0.48	0.48	32.639117

PROJECT	WALLS PARALLEL TO FLOW										
	LENGTH6 (ft)	THICKNESS6 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO6 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO6 hor.	COVER6 I.F. (in)	COVER6 O.F. (in)	AREA OF SHEAR WALLS6 (ft^2)
ALAMO											
PAINTED ROCK											0
WHITLOW											
BROKEN BOW											0
COUNCIL GROVE											0
PINE CREEK											0
WAURIKA	17	2	#9@12	#9@12	0.0069444	#10@6	#10@6	0.0176389	4	4	34
WISTER											0
W. KERR SCOTT											0
LUCKY PEAK	41.33	5	#10@6	#10@6	0.0070555	#8@12	#8@12	0.0021944	4	4	206.65
ARKABUTLA											0
APPLEGATE											0
BLUE RIVER											0
COUGAR											0
FALL CREEK											0
HILLS CREEK											0
LOST CREEK											0
HOWARD HANSON	16	1.5	#5@13	#5@13	0.0026496	#5@11.5	#5@11.5	0.002995	4	4	24
											0
MUD MOUNTN											
RIRIE											0
CERRILOS											
BLACK BUTTE											0
BUCHANNAN											0
ENGLEBRIGHT											
FARMINGTON											0
HIDDEN											0
MARTIS CREEK											
NEW HOGAN											
SUCCESS											0
TERMINUS											0
FULLERTON											0
PRADO											0
SAN ANTONIO											
SANTA FE											
CARBON CANY.											
COYOTE VALLEY											0
ISABELLA											0
ISABELLA (AUX)											0
WARM SPRINGS											
AVERAGE	16.868571	2.5357			0.0034824			0.004582	3.083	3.083	5.3235197
std. dev.	10.785796	1.3455			0.0023209			0.0060577	0.671	0.671	25.897943

INTAKE TOWERS

WALLS PERPENDICULAR TO FLOW

PROJECT	LENGTH1 (ft)	THICKNESS1 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO1 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO1 hor.	COVER1 I.F. (in)	COVER1 O.F. (in)	AREA OF SHEAR WALLS1 (ft^2)
ALAMO											
PAINTED ROCK	21	4	#10@12	#10@12	0.0044097	#8@12	#8@12	0.0027431	3	4	84
WHITLOW											
BROKEN BOW	52	6.2	#8@12	#8@12	0.0017697	#8@12	#8@12	0.0017697	3	3	322.4
COUNCIL GROVE											0
PINE CREEK											0
WAURIKA	30.5	3.5	#9@12	#9@12	0.0039683	#9@12	#9@12	0.0039683	4	4	106.75
WISTER											0
W. KERR SCOTT	30	3	#6@12	#6@12	0.002037	#7@8	#8@5	0.006417	3	3	90
LUCKY PEAK	55	5	#8@12	#8@12	0.002194	#8@12	#10@12	0.002861	4	4	275
ARKABUTLA	45.5	2	#6@24	#6@24	0.0015278	#6@12	#7@8	0.0046528	4	4	91
APPLEGATE											0
BLUE RIVER											0
COUGAR											0
FALL CREEK	23	7.75	#6@12	#6@12	0.0007885	#9@12	#9@12	0.0032912	4	4	178.25
HILLS CREEK											0
LOST CREEK											0
HOWARD HANSON	35.5	2.5	#8@13	#8@13	0.0040513	#8@11.5	#8@11.5	0.0045797	4	4	88.75
	40.33	1.75	#8@13	#8@13	0.0057875	#6@8	#5@11	0.003961	2.5	2.5	70.5775
MUD MOUNTN											
RIRIE											0
CERRILOS											
BLACK BUTTE	38.5	4	#6@12	#6@12	0.0015278	#7@6	#7@6	0.0041666	3	3	154
BUCHANNAN											0
ENGLEBRIGHT											
FARMINGTON	24	2	#6@12	#6@12	0.003055	#6@12	#6@12	0.0030555	3	3	48
HIDDEN											0
MARTIS CREEK											
NEW HOGAN											
SUCCESS	30	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037	3	3	90
TERMINUS											0
FULLERTON	22.03	1.71	#6@12	#6@12	0.003574	#6@12	#6@12	0.003574	3	3	37.6713
PRADO											0
SAN ANTONIO											
SANTA FE											
CARBON CANY.	27.17	3.58	#11@12	#11@12	0.006052	#11@9	#11@12	0.0070608	3	3	97.2686
COYOTE VALLEY											0
ISABELLA											0
ISABELLA (AUX)											0
WARM SPRINGS											
AVERAGE	33.525925	3.7081			0.0026178			0.0035538	3.32	3.39	94.899639
std. dev.	10.456838	3.0583			0.001478			0.0015091	0.656	0.652	133.16898

WALLS PERPENDICULAR TO FLOW

PROJECT	LENGTH2 (ft)	THICKNESS2 (ft)	VERT. STL INSIDE FACE (in^2)	VERT. STEEL OUTSIDE FACE	RHO2 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO2 hor.	COVER2 I.F. (in)	COVER2 O.F. (in)	AREA OF SHEAR WALLS2 (ft^2)
ALAMO											
PAINTED ROCK	21	4	#10@12	#10@12	0.0044097	#8@12	#8@12	0.0027431	3	4	84
WHITLOW											
BROKEN BOW	52	4	#8@12	#8@12	0.002743	#10@12	#10@12	0.0044097	3	3	208
COUNCIL GROVE											0
PINE CREEK											0
WAURIKA	30.5	2.75	#9@12	#9@12	0.0050505	#9@12	#9@12	0.0050505	4	4	83.875
WISTER											0
W. KERR SCOTT	30	2	#6@12	#6@12	0.003056	#9@8	#10@5	0.01592	3	3	60
LUCKY PEAK	55	4	#8@12	#8@12	0.002743	#8@12	#10@12	0.0035764	4	4	220
ARKABUTLA	45.5	2	#6@24	#6@24	0.0015278	#6@12	#7@8	0.0046528	4	4	91
APPLEGATE											0
BLUE RIVER											0
COUGAR											0
FALL CREEK	23	4.22	#8@12	#8@12	0.0026	#9@12	#9@12	0.0032912	4	4	97.06
HILLS CREEK											0
LOST CREEK											0
HOWARD HANSON	35.5	2.5	#8@13	#8@13	0.0040513	#8@11.5	#8@11.5	0.0045797	4	4	88.75
	32.5	1.75	#8@13	#8@13	0.0057875	#6@8	#5@11	0.003961	2.5	2.5	56.875
MUD MOUNTN											
RIRIE											0
CERRILOS											
BLACK BUTTE	38.5	4	#6@12	#6@12	0.0015278	#7@6	#7@6	0.0041666	3	3	154
BUCHANNAN											0
ENGLEBRIGHT											
FARMINGTON	24	2	#6@12	#6@12	0.003055	#6@12	#6@12	0.0030555	3	3	48
HIDDEN											0
MARTIS CREEK											
NEW HOGAN											
SUCCESS	30	3	#6@12	#6@12	0.002037	#6@12	#6@12	0.002037	3	3	90
TERMINUS											0
FULLERTON	22.03	1.74	#6@12	#6@12	0.0035121	#6@12	#6@12	0.0035121	3	3	38.3322
PRADO											0
SAN ANTONIO											
SANTA FE											
CARBON CANY.	27.17	3.58	#11@12	#11@12	0.006052	#11@9	#11@12	0.0070608	3	3	97.2686
COYOTE VALLEY											0
ISABELLA											0
ISABELLA (AUX)											0
WARM SPRINGS											
AVERAGE	33.516728	2.9899			0.0028349			0.0037975	3.32	3.38	75.822624
std. dev.	10.150228	1.2413			0.0014499			0.0021595	0.656	0.663	74.016221

INTAKE TOWERS

WALLS PERPENDICULAR TO FLOW

PROJECT	LENGTH3 (ft)	THICKNESS3 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO3 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO3 hor.	COVER3 I.F. (in)	COVER3 O.F. (in)	AREA OF SHEAR WALLS3 (ft^2)
ALAMO	21	1.17	#4@12	#4@12	0.002381	#4@12	#4@12	0.002381	3	3	24.57
PAINTED ROCK											
WHITLOW	52	4	#8@12	#8@12	0.002743	#8@12	#11@12	0.0040799	3	3	208
BROKEN BOW											0
COUNCIL GROVE											0
PINE CREEK	30.5	2.58	#8@12	#8@12	0.0042473	#8@12	#8@12	0.0042473	4	4	78.69
WAURIKA											0
WISTER											0
W. KERR SCOTT											
											0
LUCKY PEAK	45.5	2	#6@24	#6@24	0.0015278	#7@8	#6@12	0.0046527	4	4	91
ARKABUTLA											0
APPLEGATE											0
BLUE RIVER											0
COUGAR											0
FALL CREEK											0
HILLS CREEK											0
LOST CREEK											0
HOWARD HANSON											0
MUD MOUNTN											
RIRIE											0
CERRILOS											
BLACK BUTTE	38.5	1.5	#10@18	#10@18	0.0078395	#5@14	#5@14	0.00246	3	3	57.75
BUCHANNAN											0
ENGLEBRIGHT											0
FARMINGTON											0
HIDDEN											
MARTIS CREEK											
NEW HOGAN	16.5	2	#6@12	#6@12	0.0030555	#6@12	#6@12	0.0030555	3	3	33
SUCCESS											0
TERMINUS											0
FULLERTON											0
PRADO											
SAN ANTONIO											
SANTA FE											
CARBON CANY.											0
COYOTE VALLEY											0
ISABELLA											0
ISABELLA (AUX)											
WARM SPRINGS											
AVERAGE	31.71	2.1189			0.0033674			0.0038226	3.386	3.409	23.240072
std. dev.	9.8311223	0.6563			0.0023078			0.001252	0.61	0.576	42.147621

WALLS PERPENDICULAR TO FLOW

PROJECT	LENGTH4 (ft)	THICKNESS4 (ft)	VERT. STEEL INSIDE FACE	VERT. STEEL OUTSIDE FACE	RHO4 vert.	HOR. STEEL INSIDE FACE	HOR. STEEL OUTSIDE FACE	RHO4 hor.	COVER4 I.F. (in)	COVER4 O.F. (in)	AREA OF SHEAR WALLS4 (ft^2)
ALAMO											0
PAINTED ROCK											
WHITLOW											0
BROKEN BOW											0
COUNCIL GROVE											0
PINE CREEK	30.5	2.5	#8@12	#8@12	0.0043888	#8@12	#8@12	0.0043888	4	4	76.25
WAURIKA											0
WISTER											0
W. KERR SCOTT											
											0
LUCKY PEAK	45.5	2	#6@24	#6@24	0.0015278	#7@8	#6@12	0.0046527	4	4	91
ARKABUTLA											0
APPLEGATE											0
BLUE RIVER											0
COUGAR											0
FALL CREEK											0
HILLS CREEK											0
LOST CREEK											0
HOWARD HANSON											0
MUD MOUNTN											
RIRIE											0
CERRILOS											
BLACK BUTTE											0
BUCHANNAN											0
ENGLEBRIGHT											0
FARMINGTON											0
HIDDEN											
MARTIS CREEK											
NEW HOGAN	15.5	1.5	#6@12	#6@12	0.004074	#6@12	#6@12	0.004074	3	3	23.25
SUCCESS											0
TERMINUS											0
FULLERTON											0
PRADO											
SAN ANTONIO											
SANTA FE											
CARBON CANY.											0
COYOTE VALLEY											0
ISABELLA											0
ISABELLA (AUX)											
WARM SPRINGS											
AVERAGE	30.279	2.077			0.0023473			0.0037619	3.444	3.444	9.2869079
std. dev.	10.033751	0.4963			0.0009844			0.0011483	0.354	0.354	27.294934

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13.ABSTRACT *(Maximum 200 words)*

Existing Corps intake towers were designed using the seismic coefficient method which incorrectly estimates demands placed on an intake tower during a major earthquake. Lightly reinforced concrete structures, such as Corps' intake towers, may have sufficient inherent ductility to respond without failure. However, the success of the tower in resisting failure is dependent upon the magnitude of the earthquake loads and the structural details controlling the nonlinear dynamic response and failure mechanisms of the specific tower. Currently available analysis tools and engineering guidance for intake towers do not properly include these factors. The development and validation of better tools and guidance is the primary goal of Research Program 387 - Earthquake Engineering - Structures, Work Unit 32911, Nonlinear Dynamic Response and Failure Mechanisms of Intake Towers. The research discussed in this report is an initial step in a planned 7-year effort to accomplish this goal.

Specifically, the objective of this initial research was to quantify the distribution and variation of the structural characteristics of the Corps' inventory of existing intake towers, considering their earthquake location hazard. This was accomplished by the examination of the structural as-built drawings for 77 towers located in seismic zones 2 and above, the generation of a database containing 36 parameters for each of the towers, and a statistical analysis to summarize the distribution of these parameters.

14.SUBJECT TERMS

Ductility	Outlet works
Earthen dams	Reinforced concrete structures
Earthquake	Structural characteristics
Intake towers	

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